CHINA-US

CHINESE ACADEMY OF SCIENCES AND U.S. DEPARTMENT OF ENERGY

COOPERATION IN NUCLEAR ENERGY SCIENCES AND TECHNOLOGIES

FIRST EXECUTIVE COMMITTEE MEETING

October 22, 2012
Shanghai, China

Summary Meeting Report

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1. Introduction

Nuclear energy is an indispensable energy source for mitigating the threats of climate change as well as ensuring energy security. In June 2011, Dr. Peter Lyons, Assistant Secretary for Nuclear Energy, U.S. Department of Energy (DOE) met with Dr. Mianheng Jiang, then Vice President of the Chinese Academy of Sciences (CAS) in Beijing, China. Drs. Lyons and Jiang both recognized the growing need for developing nuclear energy as a clean and emission-free energy sources and the importance of nuclear safety. Both sides also agreed that further collaboration in nuclear science and technology will advance innovative nuclear technology developments and enhance nuclear safety objectives for both countries.

Subsequently, Dr. Zhiyuan Zhu of CAS and Dr. Stephen Kung of DOE were appointed as the lead contact persons to explore and develop an implementation mechanism for the collaboration. In September 2011, a draft Memorandum of Understanding (MOU) Agreement for Cooperation in Nuclear Energy Sciences and Technologies between DOE and CAS was presented by Dr. Kung to CAS in Shanghai. In November 2011, a CAS delegation led by Dr. Zhiyuan Zhu visited Washington D.C. and Oak Ridge National Laboratory in Tennessee, USA. During this visit, the MOU agreement was finalized by both sides.

Dr. Peter Lyons and Dr. Jinghai Li, CAS Vice President, representing the respective country, signed the MOU agreement in Washington D.C. and Beijing, respectively, in December 2011. A copy of the signed CAS-DOE Nuclear Energy Sciences and Technologies agreement is included in Attachment A. The agreement establishes an official framework to enhance cooperation in nuclear energy sciences and technologies and is expected to foster nuclear energy collaborations among scientists, laboratories, research institutes, and universities of both the United States and China.

The execution of the agreement is guided by an Executive Committee consisting of a co-chair from DOE and CAS, respectively. The Executive Committee co-chairs represent their respective country to provide high-level management oversight of the cooperation activities, which are approved by the Executive Committee co-chairs on an annual basis. One technical coordinator from each country is designated to manage and oversee the execution of the approved cooperative activities. Two cooperation areas: (1) nuclear energy for non-electric applications, including materials and chemistry of molten salt coolant systems, (2) nuclear fuel resources with a focus on direct extraction of dissolve uranium from seawater, were identified as initial collaboration activities under the agreement. The area of cooperation may be expanded and revised by the Executive Committee via written consent.

Drs. Mianheng Jiang and Peter Lyons serve as the inaugurate co-chairs of the Executive Committee. Drs. Zhiyuan Zhu and Stephen Kung are designated as technical coordinators to jointly plan, coordinate, facilitate, monitor, and assess the cooperative activities that are approved by the Executive Committee. Three working groups are currently established under the auspices of the CAS-DOE Nuclear Energy Sciences and Technologies MOU agreement. They are: Molten Salt Coolant Systems Working Group, Nuclear Fuel Resources Working Group and Nuclear Hybrid Energy Systems Working Group. Working group co-chairs are

tasked to organize and implement approved collaborative activities. A current management organization structure of the MOU agreement is provided in Attachment B.

It should be noted that although the Nuclear Hybrid Energy Systems working group was managed under the nuclear energy MOU agreement, its work scope is formally governed by a Science Protocol Agreement signed between CAS and DOE in January 2011. Initially, it was the intent of both countries to include all collaborative activities under the Science Protocol Agreement. However, DOE Office of General Counsel advised that the Molten Salt Coolant Systems and the Fuel Resources activities should not be included in the Science Protocol Agreement. This is because the nuclear energy technologies may involve nuclear export control issues which are not currently covered by the scope under the DOE-CAS Science Protocol Agreement. Nevertheless, the co-chairs of the Nuclear Hybrid Energy Systems Working Group attended a Joint Coordinating Committee meeting under the Science Protocol Agreement in April 2012 in Beijing, China. At the Protocol agreement meeting, both countries agreed to continue exploring the development of hybrid system designs and identification of hybrid systems related technology gaps, needs, and potential collaboration activities.

The first Executive Committee meeting under the auspice of CAS-DOE Nuclear Energy Sciences and Technologies agreement took place at CAS' Institute for Advanced Studies Conference Center on October 22, 2012. The inaugural Executive Committee co-chairs, Drs. Mianheng Jiang and Peter Lyons, presided over the meeting. Two technical coordinators, Drs. Zhiyuan Zhu and Stephen Kung, served as the meeting moderators. Working group co-chairs from both China and U.S. delivered presentations in their pertinent areas of common interests. Working group co-chairs also summarized their past achievements and future cooperation plan. A discussion session followed immediately after the presentations from the working groups. The Executive Committee meeting agenda is provided in Attachment C with the list of meeting attendees in Attachment D.

The Executive Committee co-chairs reviewed and discussed the current status and progress of each working groups, and approved their proposed future collaborative activities. This report provides the meeting highlights and summarizes the working groups' activities.

2. Executive Committee Meeting Highlights

The Executive Committee meeting under the auspices of the CAS-DOE Nuclear Energy Sciences and Technologies MOU agreement was held on October 22, 2012, in Shanghai, China. The objectives of the meeting were for the Executive Committee co-chairs (1) to review the status and progress under the CAS-DOE Nuclear Energy Sciences and Technologies agreement, and (2) to approve future collaborative activities. Dr. Mianheng Jiang, President of the Shanghai branch, Chinese Academy of Sciences served as the official host of the Executive Committee meeting and co-chaired the meeting with Dr. Peter Lyons, Assistant Secretary for Nuclear Energy, U.S. Department of Energy. After a brief logistics announcement by Dr. Zhiyuan Zhu, the Executive Committee meeting started at 9:10 AM with an introduction of delegation members from each side.

Dr. Mianheng Jiang, on behalf of CAS, first welcomed Dr. Lyons and the U.S. delegation to the first CAS-DOE Nuclear Energy Sciences and Technologies Executive Committee meeting. In his opening remarks, Dr. Jiang indicated that CAS and DOE shared not only common interests in energy sciences, but also the forward-looking vision in addressing long-term energy challenges. The CAS-DOE Nuclear Energy Sciences and Technologies Cooperation agreement fits well with the strategic interests of both organizations.

Dr. Jiang emphasized the importance of China-U.S. nuclear energy science and technology cooperation and expressed his confidence to continue achieving success through joint efforts. He especially thanked the scientists and researchers from both sides for zealously participating in the cooperation engagements. Dr. Jiang encouraged all attendees to actively engage in the meeting discussion and provide actionable plans to strengthen the cooperation for the benefits of both countries.

Dr. Lyons, on behalf of U.S. delegation, thanked Dr. Jiang for hosting the inaugural DOE-CAS Nuclear Energy Sciences and Technologies Executive Committee meeting. Dr. Lyons stated that the Executive Committee meeting reaffirmed the commitment between the U.S. DOE and CAS in civil nuclear energy cooperation. As the two largest energy consumers in the world, the U.S. and China share the view that nuclear energy is indispensable as an energy source for combating climate change as well as ensuring energy security.

Dr. Lyons emphasized that it is the U.S. DOE's commitment to further strengthen and expand the cooperation in peaceful use of nuclear energy with China. Dr. Lyons further noted that both countries need to work together to continue enhancing nuclear safety and security so we can advance together. He very much looked forward to the progress reports and future plans presentations from the three working groups.

Mr. Jinghua Cao, CAS International Cooperation Bureau, made an added welcome speech immediately after the opening remarks. Then, Dr. Zhiyuan Zhu presented the background and timeline for the development of the Nuclear Energy Sciences and Technologies MOU agreement. Dr. Zhu's presentation also highlighted areas of cooperation, current working group breakout structure, organizational management and co-chairs responsibilities. The presentation

entitled "The CAS-DOE Cooperation in Nuclear Energy Sciences and Technologies Overview" is provided in Attachment E.

For the remainder of the day, working group co-chairs from CAS and DOE delivered presentations in their pertinent area of common interests and current activities. The three working groups also summarized the progress and future plans for the Executive Committee's review and approval. A general discussion session followed after the working groups' presentations. Detail information for each working group and its activities is documented in the next section entitled "Working Groups Summary."

The Executive Committee co-chairs recognized and commended the efforts and achievements made by the three technical working groups under the cooperation. The Executive Committee approved the proposed future collaboration activities, including the implementation details, presented by the working groups at the meeting. The technical coordinators are charged to jointly develop and oversee the approved working groups' activities.

In the closing remarks, both Drs. Lyons and Jiang noted that substantial collaborative activities have started since the agreement was signed. Both co-chairs expressed their satisfaction of the excellent teamwork and the full collaborative spirit; they were particularly encouraged to see the world's recognized experts working together to advance nuclear energy science and technology.

In their remarks, both co-chairs reemphasized that the collaboration between China and the U.S. on civil nuclear energy is a very high priority and that the CAS-DOE Nuclear Energy Sciences and Technologies MOU agreement enables both countries to further benefit by leveraging resources, scientific knowledge, and technical capabilities. They encouraged the researchers from DOE and CAS to continue coordinating and expanding joint efforts in nuclear energy developments for mutual benefits.

It is agreed that next year's Executive Committee meeting will be held in the United States. Dr. Lyons, on behalf of the U.S. DOE extended his most sincere invitation to all participants for attending the meeting next year. Currently, it is tentatively planned to hold the next meeting in October 2013 at Oak Ridge National Laboratory in Tennessee, USA. Both Drs. Jiang and Lyons look forward to another year of productive cooperation.

The first CAS-DOE Nuclear Energy Sciences and Technologies Executive Committee meeting ended at 4:00 PM. A group photo of the meeting participants was taken inside the meeting room immediately after the meeting was adjourned and is shown in Figure 1.

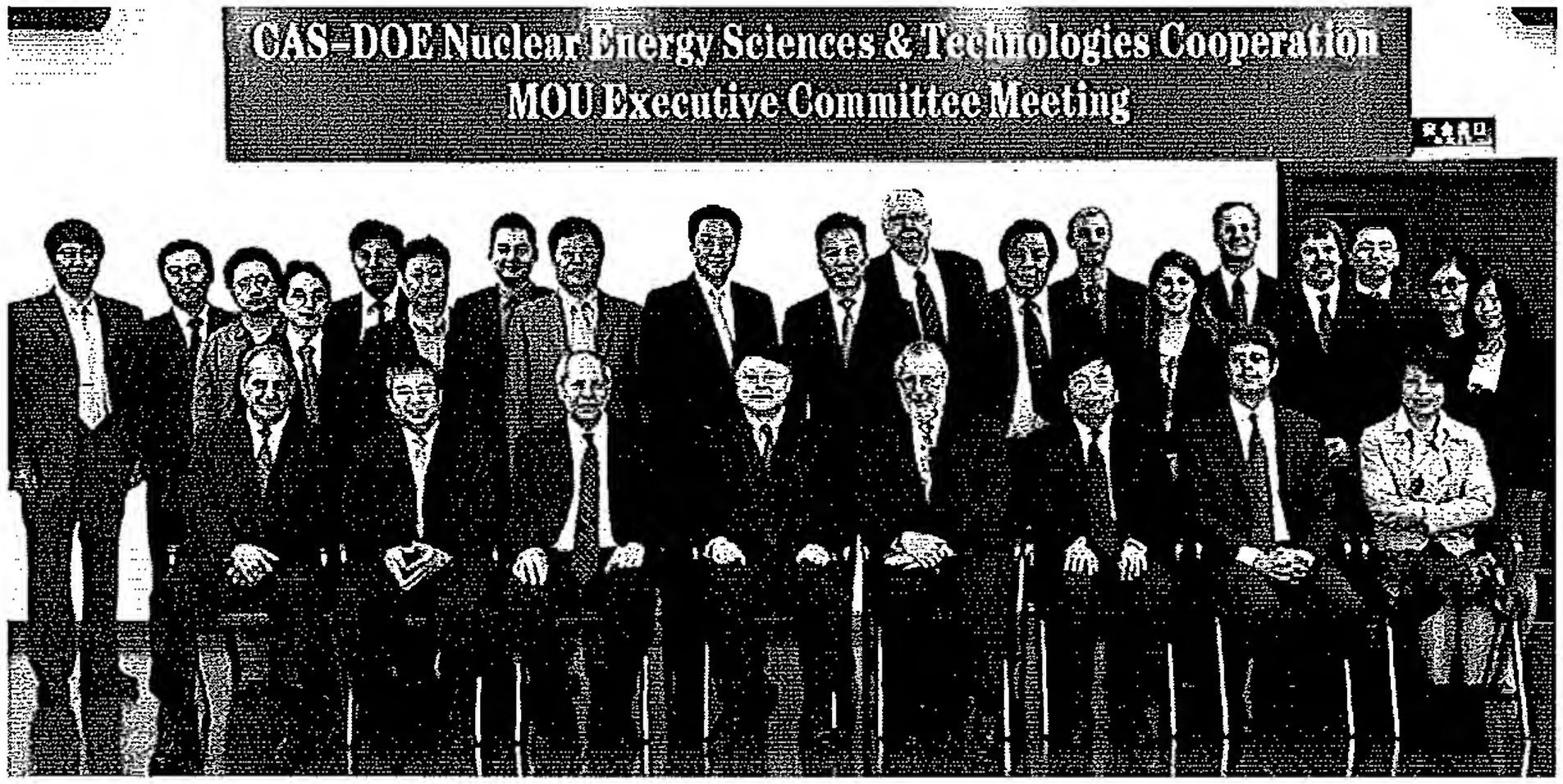


Figure 1. Participants in the first CAS-DOE Nuclear Energy Sciences and Technologies Cooperation MOU Agreement Executive Committee Meeting in Shanghai, China

On October 23, 2012, following the Executive Committee meeting, Dr. Lyons and the U.S. delegation visited the Jiading campus of the Shanghai Institute of Applied Physics (SINAP) where most of the DOE-CAS cooperative activities have been conducted. SINAP is a CAS institute of comprehensive researches in photon science, nuclear science and technology, and interdisciplinary studies, and in promoting industrial development of the scientific and technological achievements. The visit provided an opportunity to conduct a technical tour of the CAS' thorium molten salt reactor system. The U.S. delegation visited the coolant loop hydraulic and testing labs, materials research and testing facilities, molten salt chemistry and processing labs, reactor safety and computation facilities.

Accompanied by Dr. Jiang and his CAS colleagues, Dr. Lyons and some of the U.S. delegates traveled to visit the Sanmen nuclear power plant site in Sanmen County, Zhejiang Province following the SINAP visit. The Sanmen power plant site, where two Westinghouse AP1000 reactors are under construction, is the largest joint undertaking in nuclear energy between the U.S. and China. The Sanmen visit included tours of the containment and turbine buildings.

3. Working Groups Summary

This section provides a summary of the activities of each working group under the auspices of CAS-DOE Nuclear Energy Sciences and Technologies Cooperation MOU Agreement. It highlights key cooperation plans and accomplishment to date. It also documents the Executive Committee meeting presentations and discussion results, including specific proposed cooperation plans for each working group.

3.1 Molten Salt Coolant Systems

The Molten Salt Coolant Systems (MSCS) Working Group under the CAS-DOE agreement was formed to foster collaboration in areas of common interests for nuclear energy systems that use molten salt as coolant. The objectives of this working group are (1) to identify challenges and potential solutions in the areas of materials and components, salt chemistry, instrumentation, and safety for molten salt coolant systems; and (2) to jointly develop and implement research areas that will advance salt coolant technology maturity and facilitate technology deployment. This working group aims at promoting and facilitating cooperation in molten salt coolant technologies to further advance innovative high temperature nuclear energy applications.

Four technical experts currently serve as co-chairs for this working group. They are: Dr. Hongjie Xu of Shanghai Institute of Applied Physics (SINAP), Dr. Weiguang Huang of Shanghai Advanced research Institute (SARI), Dr. Cecil Parks of Oak Ridge National Laboratory (ORNL) and Dr. Charles Forsberg of Massachusetts Institute of Technology (MIT). The first information exchange meeting took place at ORNL in November 2011.

During the information exchange meeting, a 10-member Chinese delegation, led by Drs. Zhiyuan Zhu and Hongjie Xu of CAS, engaged with the U.S. researchers in a series of technical exchange presentations. Experts from each side also described the research and development (R&D) programs and highlighted technology deployment plans. The Chinese delegation toured several pertinent ORNL research facilities including the Chemistry and Materials Research labs, Molten Salt Loop Technology lab, the Spallation Neutron Source, High Flux Isotope Reactor, and the Radiochemical Engineering Development Center.

After the DOE-CAS Nuclear Energy Sciences and Technologies agreement was signed in December 2011, the first joint technical working group meeting was held in ORNL on April 11-12, 2012. During the April meeting, Dr. Hongjie Xu and his SINAP staff presented their most current program plans and shared potential collaboration scopes with the researchers from the U.S. side. The meeting identified common interests in collaborating on development and use of molten salt hydraulic test loops, conceptual plans for test reactors, component development and testing for molten salt systems, qualification of material for high temperatures (> 700 C), molten salt chemistry, and system safety and licensing issues.

The following proposed collaborative activities were discussed at the April 2012 meeting.

The US DOE has sponsored a three-year integrated research project (IRP) at universities to develop a pre-conceptual design of a fluoride-salt cooled high-temperature test reactor (FHR). As a follow up, the IRP planned to conduct workshops on FHR technologies

materials at the University of Wisconsin at Madison on August 29-30 and the test reactor requirements at MIT on November 1-2, 2012. CAS experts actively participated in these workshops and were involved in the FHR technical design discussions.

The CAS invited and hosted eight technical experts from U.S. national labs and academia to attend a technical review meeting on July 11-13 in Shanghai. The experts reviewed the CAS R&D plans for molten salt experimental flow loops and subsequent test reactors. The review team prepared a report of their observations and feedback that was submitted to CAS in October 2012. Dr. Jess Gehin of ORNL led/chaired the review team.

Dr. George Flanagan, the U.S. lead on safety and licensing of FHRs, invited CAS experts to participate in an organizing meeting on consensus of FHR safety standards. This activity was initiated under the auspices of the American Nuclear Society. The organizing meeting took place on June 24 in Chicago, IL, and a subsequent meeting was held on November 10, 2012 in San Diego, CA. Dr. Zhimin Dai of SINAP and Dr. Ed. Blandford of the University of New Mexico were named Co-Chairs for this standards activity.

The CAS is interested in utilizing Hastelloy-N, a high-temperature and corrosive-resistant material, to build a molten salt loop. Initial discussions between CAS and Haynes International on purchasing the material took place in China via Haynes' sales representatives. Since the purchase may involve U.S. export control issue, ORNL staff provided Haynes International with information on the CAS research program, and planned technology use for the material.

The CAS expressed an interest in exchange of students and early-career staff with US universities on collaborative research activities. An initial discussion was held with Dr. Per Petersen of the University of California – Berkeley (UC-B). One collaborative activity is to develop models to investigate any potential safety issues associated with the reactivity feedback mechanisms for the solid fuel Thorium Molten Salt Reactor (TMSR) baseline design. In particular, the enrichment of Li-7 was evaluated to assure a negative temperature reactivity coefficient. The possibilities of using other salts with attractive neutronic properties were also investigated. All of the UC-B analysis results were shared with the CAS. A workshop between UC-B and CAS was held on November 5-7 at UC-B to discuss molten salt heat transfer issues.

The implemented results of these activities were reported during the Executive Committee meeting on October 22, 2012. Lead working group co-chairs, Drs. Hongjie Xu and Cecil Parks also presented area of common interests and current activities from each country in the area of molten salt coolant systems during the Executive Committee meeting. The slides of the co-chairs' presentation are included in Attachment F.

The proposed future collaboration activities in the areas of molten salt coolant system development and design, FHR safety and licensing including tritium management, and studies on materials and components salt compatibility took place during the presentations. During the follow-up discussion, it was agreed that the safety standards which are applicable to molten salt cooled systems should be continued under the on-going ANS FHR Safety Standard Committee activities. In addition, it was decided that researchers should develop a joint collaboration and

evaluation plan to address the FHR hydraulic design and testing tools. A plan for experimental data and model validation needs should also be jointly pursued.

A student exchange internship program between CAS and US universities engaged in molten salt cooled reactor R&D was also discussed. Both sides decided to first develop a list of projects for the exchange students /staff to conduct. The activity may start once a mutually agreed implementation schedule is reached. It is agreed that exchange visits should be continued to strengthen the cooperation activities.

To strengthen the common interest in nuclear safety, CAS expressed a desire to explore adopting U.S. developed safety-related software for the reactor design and construction. The U.S. DOE agreed to investigate the software access options and plans to hold further discussions with CAS to identify a mutually agreeable mechanism. To further facilitate the development and deployment of CAS' Thorium Molten Salt Reactor (TMSR) program, CAS intends to establish a Cooperative Research and Development Agreement (CRADA) with ORNL in FY2013. ORNL and SINAP have initiated discussions on the implementation process. The CRADA may include activities such as review and analysis of TMSR test reactors and associated test loops designs, development of the flow meter and fission chamber, establishing a computer server at ORNL for SINAP researchers to access remotely.

CAS is also interested in exploring the study of rare earth and actinide halides chemical behaviors in molten salt during pyroprocessing. Both sides agreed to discuss the cooperation opportunity through visit of research facilities at Argonne and Idaho National Laboratories. A tutorial workshop on actinide/lanthanide concentration measurement in molten salt systems is planned to further explore the cooperation opportunity.

The agreed-to events under the auspices of Molten Salt Coolant System Working Group are shown in the table below.

China–USA Molten Salt Coolant System Working Group: Planned Milestones and Deliverables			
Task/Deliverable	**Subtask/Details**	**Location**	**Date**
Technical Meetings	Technical Information Exchange Meeting – exchange current activities in molten salt coolant systems	Oak Ridge, TN	Nov.7-8, 2011
	Working Group Meeting – experts meeting to explore potential cooperation	Oak Ridge, TN	April 12-13, 2012
	CAS program review meeting	Shanghai, China	July 11-13, 2012
	FHR Materials Workshop	Madison, WI	August 29-30, 2012
	FHR Test Reactor Requirements Workshop	Boston, MA	Nov. 1-2, 2012
	Molten Salt Heat Transfer meeting	Berkeley, CA	Nov.5-7, 2012
	2012 Executive Committee meeting	Shanghai, China	Oct. 22, 2012
	Lead Working Group Co-chairs meeting – planning of cooperation activities	San Francisco, CA	Jan. 28, 2013
	Technical visit & Information Exchange meeting	Shanghai, China	Feb. 25-26, 2013
	Working Group Meeting – discussion of current program status and development	China	April 2013
	FHR Workshop	US	TBD
	Executive Committee meeting	Oak Ridge, TN	Oct 2013
Exchanging Researchers	Initial discussion on staff exchange	US/China	2012
	UC-Berkeley staff starts working at CAS	Shanghai, China	2013
	CAS staff starts working at UC-Berkeley	Oak Ridge, TN	2013
FHR Safety Materials and Components for Molten Salt Loop	Initial Discussion on Consensus of FHR Safety Standards	Chicago, IL	June 24, 2012
	Meeting on FHR Safety and Licensing	San Diego, CA	Nov. 10, 2012

China–USA Molten Salt Coolant System Working Group: Planned Milestones and Deliverables			
Task/Deliverable	**Subtask/Details**	**Location**	**Date**
	Meeting on FHR Safety Standard and ASME Committee	TBD	2013
Materials, Chemistry and Components for Molten Salt Loop	Initial discussion on CAS Procurement of Hastelloy-N via Haynes International & Developing Purchase	US/China	2012 & 2013
	Review and Analysis of Molten Salt Test Reactors and Test Loops Designs	US/China	2013
	Evaluation and Testing of Salt Coolant Flow Meter and Fission Chamber	US/China	2013
	Discussions on TRISO Fuel and Salt Interactions	US/China	2013
	Safety and Hydraulic Analysis Software for Molten Salt Coolant Systems	US/China	2013
Molten Salt Chemistry for Pyrochemical Separations	Attending the 2012 International Pyroprocessing Conference	Fontana, WI	Aug. 26-29, 2012
	Meeting on Separation of Rare Earth and Actinide Halide in Salt and Pyro-facility Tour	Idaho falls, ID	May 2013
	Meeting for On-Line Monitoring in Molten salt and Pyro-facility Tour	Argonne, IL	May 2013
	Pyroprocessing Tutorial Workshop	Shanghai, China	2013

3.2 Fuel Resources

For nuclear energy to remain a sustainable energy source there must be assurance that an economically viable supply of nuclear fuel is available. Although uranium is present in very low concentrations in seawater (3.3 part per billion), the oceans contain over 4,500 million tons of uranium, which would last for centuries even with aggressive nuclear energy growth. Economic extraction of uranium from seawater could ensure a feasible fuel supply for nuclear power for millennia to come.

The Nuclear Fuel Resources Working Group was formed to jointly pursue the development of uranium extraction from unconventional resources. This group focuses on efforts to develop seawater uranium harvesting method. Initial cooperation centers on the following three specific topics: (1) molecular level understanding of uranium binding and computational design of new selective ligands; (2) development of advanced adsorbent materials (by radiation grafting); and (3) marine testing of the adsorbents capacity and kinetics of extraction of uranium from seawater.

Two technical experts from each country currently serve as the working group co-chairs. They are: Dr. Zhimin Dai of Shanghai Institute of Applied Physics (SINAP), Dr. Biao Jiang of Shanghai Advanced research Institute (SARI), Dr. Phil Britt of Oak Ridge National Laboratory (ORNL) and Dr. John Arnold of the University of California-Berkeley (UC-B).

Technical experts from both countries met at two information exchange meetings, one on Nov.7-8, 2011, in Oak Ridge, TN, and the other on August 20-21, 2012, in Philadelphia, PA. During the ORNL meeting in November 2011, researchers from CAS visited the Materials and Chemistry labs that are used for the development and testing of advanced adsorbents for the extraction of uranium from seawater. After the DOE-CAS Nuclear Energy Sciences and Technologies agreement was signed in December 2011, the first joint technical working group meeting was held at ORNL on April 11-12, 2012. Detailed technical information and research plans on the preparation and testing of polymeric and nanoporous carbon sorbents for the extraction of uranium from seawater were discussed during these working group and information exchange meetings.

At the Executive Committee meeting in October 2012, Dr. Phil Britt and Dr. Guozhong Wu of SINAP presented the most current R&D activities from each country. Fuel Resources Working Group also reported the following major accomplishments:

(1) Advanced Adsorbents Sample Exchange:

CAS provided four polymer samples (untreated ultrahigh molecular weight polyethylene (UHMWPE), two amidoxime functionalized UHMWPE fibers, and a poly(acrylonitrile) fiber after amidoximation) to the U.S. side for laboratory screening and marine testing of uranium adsorption. The objective is to evaluate the performance of CAS samples with the adsorbent samples prepared by ORNL.

(2) Comparison of Polymer Grafting Techniques:

Radiation grafting methods developed by the ORNL team were used to functionalize the untreated UHMWPE with amidoxime ligands. The uranium adsorption capacity of the ORNL prepared UHMWPE samples were studied side-by-side with the materials prepared by CAS in marine test experiments. ORNL also investigated the impact of radiation dosage on the mechanical properties of UHMWPE fibers obtained from CAS.

(3) Marine Sorption Kinetics Studies :

Adsorption capacity of the CAS and ORNL polymers for uranium adsorption was tested using laboratory screening methods and real seawater at the Pacific Northwest National Laboratory Marine Science Laboratory. Kinetics of uranium sorption along with other major elements found in seawater was conducted for the CAS polymers in batch and flow modes in late 2012.

(4) Exchange Information and Testing Results:

Preliminary performance results of adsorption and mechanical tests for the CAS and ORNL polymer samples were presented and discussed during the information exchange meeting in Philadelphia, PA on August 20-22, 2012.

Future plans proposed and approved during the Executive Committee meeting in Shanghai include:

(1) CAS and ORNL researchers will continue to exchange information and explore methods to synthesize polymeric adsorbents to extract uranium from seawater using e-beam and radiation induced grafting of amidoxime ligands, to test adsorbent capacity and kinetics in marine environment, and to scale up experiments.

(2) Continue the exchange of polymer samples. Both sides plan to further exchange their best samples for marine testing to determine capacity and kinetics of adsorption of uranium from seawater.

(3) Continue the planning and implementation of staff exchange in computational design. CAS plans to identify an early-career staff member to conduct research in the area of computational ligand design to improve the uranium extraction capacity. The exchange staff will start the assignment at ORNL in 2013 (under the supervision of Dr. Ben Hay).

(4) CAS and ORNL researchers are planning to publish a peer-reviewed paper on the adsorption of uranium from seawater using amidoxime functionalized UHMWPE fibers.

The agreed-to events under the auspices of Fuel Resources Working Group are shown in the table below.

China–USA Fuel Resources Working Group: Planned Milestones and Deliverables			
Task/Deliverable	**Subtask/Details**	**Location**	**Date**
Technical Meetings	Information Exchange Meeting – Exchange current activities in extraction of uranium from seawater	Oak Ridge, TN	Nov.7-8, 2011
	Working Group Meeting – Experts meeting to explore potential cooperation	Oak Ridge, TN	April 12-13, 2012
	Information Exchange Meeting – Exchange information on current activities in extraction of uranium from seawater	Philadelphia, PA	August 20, 2012
	Symposium for Seawater Uranium Extraction – Technical presentations and discussion during the American Chemical Society annual meeting	Philadelphia, PA	August 21, 2012
	Executive Committee meeting	Shanghai, China	Oct. 22, 2012
	Working Group Meeting – discuss of current program status	Sanya, Hainan, China	April 2013
	Marine Testing Site Visit	Sequim, WA,	May/June 2013
	Information Exchange Meeting – Exchange information on recent technical development	Shanghai, China	July/Aug. 2013
	Executive Committee meeting	Oak Ridge, TN	Oct. 2013
Exchanging Researchers	Exploring the mechanisms of exchanging researchers/short term visit in the areas of computation modeling and radiation grafting	US/China	2012
	CAS staff starts working at ORNL on computational ligand design	Oak Ridge, TN	2013
	ORNL staff starts working at CAS	Shanghai, China	2014
Joint Development of Adsorbent Materials	CAS prepared and shipped the adsorbent materials to ORNL for evaluation	Shanghai, China	June 2012
	ORNL functionalized UHMWPE with amidoxime ligands & investigate the impact of radiation dose on the mechanical properties	Oak Ridge, TN	July – August 2012
	Perform laboratory tests to quantify uranium sorption capacity and conducted a side-by-side tests with real seawater on CAS and ORNL UHMWPE samples	US	2012
	Discussion of the preliminary results at the information exchange meeting	Philadelphia, PA	August 20, 201
	Determine the sorption capacity and kinetics of CAS and ORNL UHMWPE samples	Sequim, WA	2012 – 2013

China–USA Fuel Resources Working Group: Planned Milestones and Deliverables			
Task/Deliverable	**Subtask/Details**	**Location**	**Date**
	Marine Science Laboratory site visit and information exchange on grafting parameters for UHMWPE	Sequim, WA	May/June 2013
	Conduct marine testing of best U.S. samples	Sanya, Hainan, China	2014
Joint Publication	Provide a list of papers published by U.S. Working Group to CAS	US	Oct. 2012 & 2013
	Develop and publish a joint peer-reviewed paper on UHMWPE materials and marine testing results	US & China	2014

3.3 Nuclear Hybrid Energy Systems

Hybrid energy systems may enable greater usage of nuclear energy and could potentially open a new opportunity for nuclear power deployment. For example, nuclear energy can be used for the hybrid of cogeneration high temperature process heat for industrial applications and electricity. Through hybrid systems, nuclear energy could potentially play an important role in the cost-effective integration of renewable energy and more efficient use of fossil energy. The goal of Nuclear Hybrid Energy Systems Working Group is to realize the full potential of hybrid concepts, to develop implementation strategies, and to conduct research activities.

Currently, work scope of the Hybrid Energy Systems Working Group is formally governed by a Science Protocol Agreement signed between CAS and DOE in January 2011. In April 2012, a Joint Coordinating Committee meeting under the Science Protocol Agreement between CAS and DOE took place in Beijing, China. The co-chairs of the Nuclear Hybrid Energy Systems Working Group, Dr. Steve Aumeier of Idaho National Laboratory (INL) and Dr. Zhiyuan Zhu of CAS attended the meeting. It was agreed that both sides will continue exploring the development of hybrid system designs and identification of hybrid systems related technology R&D gaps, needs, and potential collaboration activities. At least two workshops were conducted in the past year to develop paths forward. At present, internet conference calls between CAS and INL researchers are on-going. Short term goals are (1) to complete process analysis, (2) to explore staff exchange, and (3) to write joint journal article.

In 2012, INL and CAS held two internet conference calls to discuss collaboration interests which include: (1) Develop and analyze architectures for HES conversion of coal to synfuels; (2) Evaluate and compare the technical and environmental benefits of Light Water Small Modular Reactors (SMR), Thorium Molten Salt Reactors (TMSR), High Temperature Gas-Cooled Reactors Results (HTGR); (3) Share models and results of High Temperature Steam Electrolysis (HTSE) tests; and (4) Publish a research paper together on the outcomes of the analysis and impact on cost of energy, environmental benefits, and water savings. Both sides tentatively agree to consider the following topics for the near-term cooperation: (1) Hydrogen production by high temperature electrolysis; and (2) Simulating of Hybrid Energy System.

The agreed-to events under the auspices of Nuclear Hybrid Energy Systems Working Group are shown in the table below.

China–USA Nuclear Hybrid Energy Systems Working Group: Milestones and Deliverables			
Task/Deliverable	**Subtask/Details**	**Location**	**Date**
Technical Meetings	CAS-DOE Science Protocol Joint Coordinating Committee meeting	Beijing, China	April 19-20, 2012
	SINAP Staff visited INL – discussion on hydrogen production	Idaho falls, ID	March 19-22, 2012

China–USA Nuclear Hybrid Energy Systems Working Group: Milestones and Deliverables			
Task/Deliverable	**Subtask/Details**	**Location**	**Date**
	Hybrid Energy System Workshop	Salt Lake City, UT	April 3-4, 2012
	INL staff visited SINAP and SARI	Shanghai, China	June 11, 2012
	Tele Video Conference - Review and Discuss potential Work Statement	US/China	July 12, 2012
	Web-Based Information Exchange Video Conference	US/China	Sept.6, 2012
Phase I of Hybrid Energy System Study	HES Analysis	US/China	Nov 30, 2012
	Conclusion Phase I technical and economical assessments	US/China	March 30, 2013
	Prepare a Journal Publication	US/China	June 30, 2013
	Wrap-up Discussions and Memorandum	US/China	Sept.30, 2013

Attachment A:

Signed CAS-DOE Cooperation in Nuclear Energy Sciences and Technologies Memorandum of Understanding Agreement

MEMORANDUM OF UNDERSTANDING

BETWEEN

THE DEPARTMENT OF ENERGY
OF THE UNITED STATES OF AMERICA

AND

THE CHINESE ACADEMY OF SCIENCES

ON COOPERATION IN NUCLEAR ENERGY SCIENCES AND TECHNOLOGIES

The Department of Energy (DOE) of the United States of America, and the Chinese Academy of Sciences (CAS) of the People's Republic of China, hereinafter referred to as the "Participants":

NOTING their desire to enhance communication and cooperation on nuclear energy-related matters of common interest and to foster collaboration among scientists, laboratories, research institutes and universities of the Participants' countries and to facilitate and promote cooperation in research and development in a broad range of nuclear energy sciences and technologies; and

NOTING the Agreement for Cooperation between the Government of the United States of America and the Government of the People's Republic of China Concerning Peaceful Uses of Nuclear Energy, signed at Washington on July 23, 1985,

Have reached the following understanding:

Section 1
Objective

1. The objective of this Memorandum of Understanding (Memorandum) is to promote and facilitate cooperation on the scientific and technical aspects of nuclear energy technologies.

2. By their joint determination, the Participants may invite other entities to participate in the cooperative activities carried out in the framework of this Memorandum: governmental agencies, universities, science and research centers, institutes and institutions, private sector firms, and other entities of the Participants' respective governments. The costs of such participation are the responsibility of the entities that incur them.

3. The Participants' cooperation under this Memorandum is intended for peaceful purposes only.

Section 2
Forms of Cooperation

1. Forms of cooperation under this Memorandum may include: exchange of publicly available technical information, data and experience; exchange of technical and managerial personnel for visits and short-term assignments; exchange of equipment, materials and instrumentation; joint conferences, seminars or workshops; and such other forms of cooperation as the Participants may jointly decide in writing.

2. The terms of visits and assignments, and the exchange of equipment, materials, and instrumentation should be the subjects of appropriate written agreements between the sending and receiving entities.

Section 3
Areas of Cooperation

1. Priority areas of cooperation may include the following:

<u>Nuclear Energy for Non-electric Applications</u>
Nuclear power could be used to displace greenhouse gas emitting fuels in the industrial sector. Petroleum refining, for example, requires temperatures in the range of 250-500°C while steam reforming of natural gas requires process heat in the 500-900°C range. Achieving higher output temperatures requires switching to a new coolant technology such as molten salt. With advanced coolants, it is possible to achieve outlet temperatures ranging from 500°C to over 900°C.

Potential subjects of collaborative activities may include materials and chemistry of fluoride salt coolant systems.

Nuclear Fuel Resources
Nuclear energy can help alleviate the concern over greenhouse gases and global warming, energy supply security, and high and volatile fossil fuel prices. For nuclear energy to remain a viable and sustainable energy source, there must be assurance that economical sources of nuclear fuels are available. The focus of this cooperation is direct extraction of dissolved uranium from seawater. Although uranium is present in very low concentrations in seawater, 3.3 parts per billion, the oceans contain over 4500 million tonnes of uranium, which would provide essentially unlimited supply of nuclear fuel. Potential subjects of collaborative activities may include: (a) molecular-level understanding of the coordination modes, sorption mechanisms, and kinetics of uranium extraction; (b) new functional ligands; and (c) advanced sorbent materials.

2. The areas of cooperation may be expanded and revised by the written consent of the Participants.

3. The Participants intend to conduct research and development on mutually determined subjects under appropriate written agreements therefor. Such agreements should include, among other matters, provisions for the protection and allocation of intellectual property.

Section 4
Management

1. Execution of this Memorandum is to be guided by an Executive Committee (EC) consisting of one co-chair from each Participant: DOE Assistant Secretary for Nuclear Energy and Vice President of CAS.

2. The EC co-chairs should designate one technical coordinator from each Participant to organize technical activities under this Memorandum. The technical coordinators should jointly plan, identify, and coordinate cooperative activities. Specific working groups may be established to collaborate on mutually determined topics.

3. Working groups and/or EC meetings should take place on an annual basis or as otherwise mutually decided, alternately in the United States and in the People's Republic of China.

4. The host Participant should choose the meeting site and bear the costs for the arrangements associated with the meeting. Representatives from each Participant attending the meetings are to be responsible for their own travel and lodging expenses.

5. The technical coordinators should jointly prepare written reports of the meetings. Each Participant may disseminate the written meeting report without prior notification to the other Participant, after the record has been approved by EC. The report should document the progress of activities and the next year's plans for continuation of cooperation.

6. The technical coordinators may invite representatives of other organizations within their countries to attend joint working groups and/or EC meetings.

Section 5
General Considerations

1. This Memorandum does not constitute a legally binding agreement.

2. Each Participant should implement this Memorandum in accordance with the laws, regulations and other requirements of its respective country and international agreements to which its government is party.

3. Any questions relating to this Memorandum arising during its term should be resolved by consultations between the Participants.

4. Each Participant is responsible for the costs of its participation in all cooperative activities carried out in the framework of this Memorandum, unless they determine otherwise in writing. Each Participant's participation in the cooperative activities is subject to the availability of funds, resources, and personnel.

Section 6
Commencement, Modification, and Discontinuation

1. The Participants' implementation of cooperative activities within the framework of this Memorandum may commence on the date of signature.

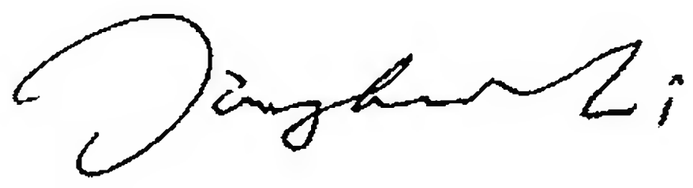
2. This Memorandum may be modified by mutual determination of the Participants in writing.

3. The Participants may discontinue this Memorandum at any time in writing. Alternatively, a Participant that wishes to discontinue its participation in the activities under this Memorandum should endeavor to provide at least six (6) months' written notice to the other Participant.

Signed, in duplicate, at Washington on the 21 day of December, 2011, and at Beijing on the 29 day of December, 2011, in the English and Chinese languages.

FOR THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA:

FOR THE CHINESE ACADEMY OF SCIENCES:



谅解备忘录

美利坚合众国 能源部

与

中国科学院

关于核能科学与技术合作

美利坚合众国能源部（能源部）和中华人民共和国科学院（中科院），以下简称"双方"：

注意到双方对在核能方面共同关注事宜加强沟通与合作，促进双方的科学家、实验室、研究机构和大学间的合作，和实现广泛的核能科学与技术领域的研发合作上的愿望；并

注意到于 1985 年 7 月 23 日在华盛顿签署的美利坚合众国政府与中华人民共和国政府关于和平利用核技术的合作协议，

达成以下谅解：

一、目标

1. 本谅解备忘录（备忘录）旨在推进和加快核能技术领域的科技方面的合作。

2. 经共同确认后，双方可以邀请其他单位参与在此备忘录框架下开展的合作活动，包括：政府机构、大学、科研中心、研究院所、私人企业和双方各自政府下的其他单位。其所需费用由参与单位自行负担。

3. 双方在此备忘录下的合作均仅限于和平目的。

3． 双方将在以书面协议形式共同确定的领域进行研究和开发工作。此类协议其中，涵盖的其他事宜当中，应包括保护和分配知识产权的条款。

四、管理

1. 对本备忘录的执行将受执行委员会的监督，执行委员会包括双方各一名主席，即能源部核能助理部长和中科院副院长。

2. 执行委员会主席应从本方各自指派一名技术协调员执行本备忘录下的相关技术活动。双方技术协调员应共同计划、确定和协调合作活动，并可针对双方共同确立的课题成立相关工作组。

3. 工作组和/或执行委员会会议每年举办一次或按双方商定择期举办，会议轮流在美国和中国举行。

4. 主办方应负责选择会议的地点并承担会议相关的费用。参与会议的双方代表应承担各自的旅费和住宿费用。

5. 双方的技术协调员应共同撰写会议报告，经执行委员会批准后，双方均有权发布会议书面报告，无需事先通知对方。会议报告应包含双方合作活动的进展情况，以及下一年延续合作的实施计划。
6. 技术协调员可以邀请其本国其他机构的代表参加工作组和/或执行委员会会议。

五、总体考虑

1. 本备忘录将不受法律约束。

2. 任何一方在本备忘录下所开展的活动均须遵守其相关法律、规定和要求，以及本国所加入的国际协议。

Attachment B:

CAS-DOE Nuclear Energy Cooperation Agreement Organizational Overview and Responsibilities

Organizational Overview

The Chinese Academy of Sciences (CAS) and U.S. Department of Energy (DOE)
Nuclear Energy Cooperation Memorandum of Understanding (MOU)

MOU Executive Committee Co-Chairs
China – Mianheng Jiang (CAS) 江绵恒
U.S. – Peter Lyons (DOE)

Technical Coordination Co-Chairs
China – Zhiyuan Zhu (CAS) 朱志远
U.S. – Stephen Kung (DOE)

Molten Salt Coolant Systems
- Hongjie Xu (SINAP, CAS) 徐洪杰
  Weiguang Huang (SARI,CAS) 黄伟光
- Cecil Parks (ORNL)
  Charles Forsberg (MIT)

Nuclear Hybrid Energy Systems *
- Zhiyuan Zhu (CAS) 朱志远
  Yuhan Sun (SARI,CAS) 孙予罕
- Steven Aumeier (INL)

Nuclear Fuel Resources
- Zhimin Dai (SINAP, CAS) 戴志敏
  Biao Jiang (SARI,CAS) 姜标
- Phil Britt (ORNL)
  John Arnold (UC-Berkeley)

* **Work scope governed by DOE-CAS Science Protocol Agreement**

SINAP: Shanghai Institute of Applied Physics
SARI: Shanghai Advanced Research Institute
ORNL: Oak Ridge National Laboratory
INL: Idaho National Laboratory
MIT: Massachusetts Institute of Technology
UC-Berkeley: University of California at Berkeley

CAS- DOE Nuclear Energy Collaboration
Co-Chairs Responsibilities

Executive Committee

- Chair annual Executive Committee meeting
- Review working groups' accomplishments
- Approve proposed outyear R&D activities
- Provide guidance on long-term cooperation directions

Technical Coordination

- Coordinate with working groups to establish implementation plan
- Propose and identify new collaboration topics and potential opportunities
- Monitor, facilitate, and assess technical progress of the R&D activities
- Chair Joint Technical Working Groups meeting, if Executive Committee meeting is not scheduled

Working Group

- Chair annual Working Group meetings
- Organize and implement approved collaborative activities
  (e.g., training, workshop, information exchange meeting, perform R&D tasks)
- Present accomplishments at Executive Committee meetings
- Document and prepare meeting records and progress reports

Attachment C:

Executive Committee Meeting Agenda

Executive Committee Meeting Agenda

CAS-DOE Nuclear Energy Sciences & Technologies Cooperative Agreement
Co-Chairs: Drs. Mianheng Jiang and Peter Lyons

October 22, 2012
Shanghai, China

Moderators: Zhiyuan Zhu and Stephen Kung		
9:00 - 10:15	Introduction and Announcement	Zhiyuan Zhu
	Welcome and Opening Remarks	Mianheng Jiang
	Opening Remark	Peter Lyons
	Added Welcome Speak	Jinghua Cao
	Agenda Overview, Meeting Goal and CAS-DOE Nuclear Energy Collaboration Overview	Zhiyuan Zhu Stephen Kung
10:15 - 11:00	Working Group Presentation (1) Molten Salt Coolant Systems Working Group Status and Accomplishments Future Plan and Discussion	Lead co-chairs: Hongjie Xu Cecil Parks
11:00 - 11:30	Coffee break	
11:30 - 12:15	Working Group Presentation (2) Fuel Resources Working Group Status and Accomplishments Future Plan and Discussion	Lead co-chairs: Guozhong Wu Phil Britt
12:15 - 13:30	Working Lunch	
13:30 - 14:15	Working Group Presentation (3) Nuclear Hybrid Energy Systems Working Group Status and Accomplishments Future Plan and Discussion	Lead co-chairs: Zhiyuan Zhu
14:15 - 15:00	General Discussion FHR Safety Standard	Zhimin Dai
15:00 - 15:30	Coffee break	
15:30 - 16:00	Closing Remarks	Peter Lyons Mianheng Jiang
16:00	Adjourn	
16:00 - 16:20	Group Photograph	
18:00 - 19:30	Welcoming dinner hosted by Dr. Mianheng Jiang	

Attachment D:

List of Executive Committee Meeting Attendees

Attendees List
Executive Committee Meeting
CAS-DOE Nuclear Energy Sciences & Technologies Cooperative Agreement

China

Jiang, Mianheng	President, Shanghai Branch CAS, Executive Committee China Co-chair
Liu, Minghua	Director, Bureau of Basic Research, CAS
Cao, Jinghua	Deputy Director, Bureau of International Cooperation, CAS
Liu, Guiju	Deputy Director, Bureau of High-Tech Research and Development
Zhu, Zhiyuan	Vice President, Shanghai Branch CAS, Technical Coordination Committee China Co-chair
Xu, Hongjie	Director, TMSR Center, SINAP, Molten Salt Coolant Systems Working Group China Co-chair
Dai, Zhimin	Deputy Director, SINAP and TMSR Center, Nuclear Fuel Resources Working Group China Co-chair
Sun, Yuhan	SARI Vice President, Nuclear Hybrid Energy Systems Working Group China Co-chair
Jiang, Biao	SARI Vice President, Nuclear Fuel Resources Working Group China Co-chair
Wu, Guozhong	Division Director, Radiation Chemistry, SINAP
Yu, Xiaohan	Division Director, Reactor Physics, SINAP
Zhang, Qinqquan	Director for America and Oceania Partners, CAS Bureau of International Cooperation
Xie, Leidong	Deputy Division Director, Molten Salt Chemistry and Engineering, SINAP
Chen, Kun	Deputy Division Director, Nuclear Safety, SINAP
Wang, Jiang	Staff, CAS Shanghai Branch
Zhu,Tailai	Staff, CAS Shanghai Branch

U.S.

Pete Lyons	DOE Assistant Secretary, Executive Committee US Co-Chair
John Kelly	Deputy Assistant Secretary for Nuclear Reactor Technologies, DOE
Liz Ramsay	Special Policy Advisor, DOE Office of Nuclear Energy
Stephen Kung	DOE Program Manager, Technical Coordination Committee US Co-Chair
Thom Mason	Laboratory Director, Oak Ridge National Laboratory
Cecil Parks	ORNL Division Director, Molten Salt Coolant Systems Working Group US Co-Chair
Phil Britt	ORNL Division Director, Nuclear Fuel Resources Working Group US Co-Chair
Charles Forsberg	Massachusetts Institute of Technology, Molten Salt Coolant Systems Working Group US Co-Chair
John Arnold	Univ of California-Berkeley, Nuclear Fuel Resources Working Group US Co-Chair
Martin Schoenbauer	Office Director, DOE-Beijing
Jun Shao	Senior Analyst, DOE-Beijing
Seth Patch	ESTH Consul, US Consulate General Shanghai

Attachment E:

CAS-DOE Cooperation in Nuclear Energy Sciences and Technologies Overview Presentation

Slide 1

CAS-DOE
Cooperation in Nuclear Energy Sciences and Technologies

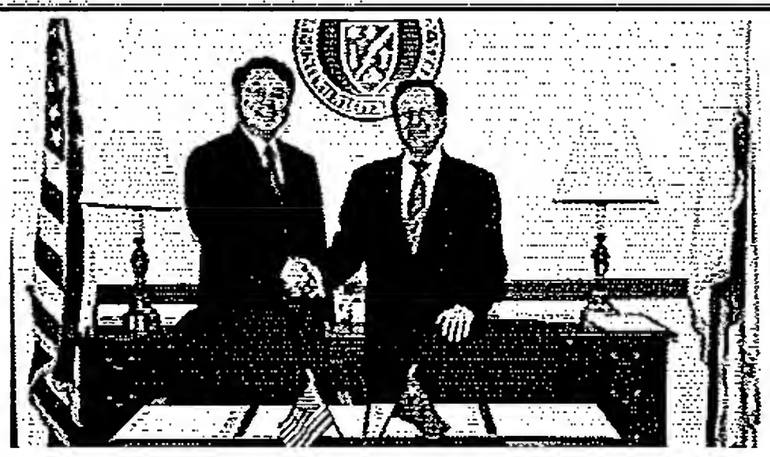
Overview

Technical Coordination Co-Chairs
Zhiyuan Zhu, CAS
Stephen Kung, DOE

October 22, Shanghai

Slide 2

Significant Moment for the China-U.S Bilateral Collaboration



Dr. Mianheng Jiang and Dr. Steven Koonin signed *the Protocol Agreement between the U.S. Department of Energy and P.R. of China Chinese Academy of Sciences for Cooperation in Energy Sciences* on Jan.19, 2011 in Washington, D.C.
This is the first Science Protocol Agreement between CAS and DOE to promote and facilitate the bilateral collaboration in broad energy sciences.

Slide 3

Significant Moment for the China-U.S Bilateral Collaboration

- On June 9, 2011, Dr. Mianheng Jiang, then CAS Vice President, met with Dr. Pete Lyons, DOE Assistant Secretary for Nuclear Energy in Beijing.

Slide 4

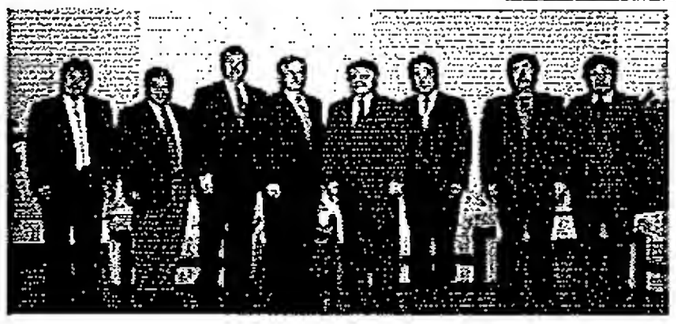
Significant Moment for the China-U.S Bilateral Collaboration

- Both sides recognized the growing need for developing nuclear energy as a clean and emission-free energy sources and the importance of nuclear safety. It was agreed that further cooperation in nuclear science and technology will advance innovative nuclear technology developments as well as enhancing nuclear safety objective for both the United States and the People's Republic of China.
- Both sides decided to explore cooperation mechanisms. Specifically, CAS Institutes work with ORNL in the area of molten salt coolant systems and seawater uranium extraction and with INL in hybrid energy systems.
- Drs. Zhiyuan Zhu and Stephen Kung were designated as technical coordinators to initiate and implement the cooperation.

Slide 5

Exchange Visits – DOE lab managers visited CAS

Dr. Thom Mason, Oak Ridge National Laboratory Director, visited CAS Shanghai Institute of Applied Physics in May 2011



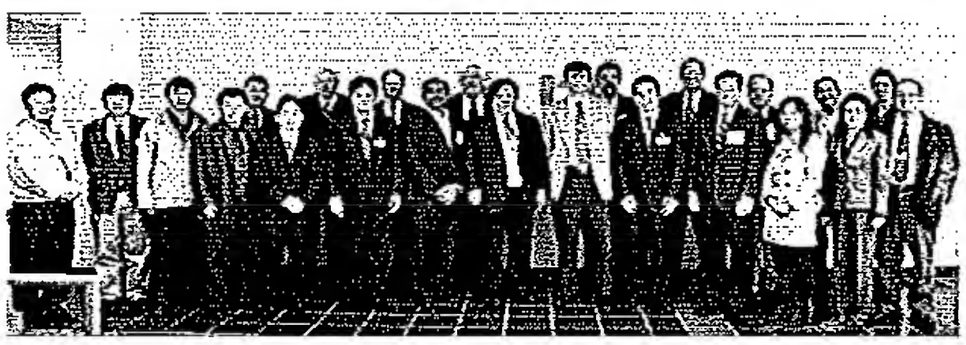
Dr. John Grossenbacher, Idaho National Laboratory Director, and the Idaho lab delegation visited Shanghai CAS in December 2011

Slide 6

Exchange Visits – CAS visited DOE laboratories

CAS delegation visited INL
June 2011

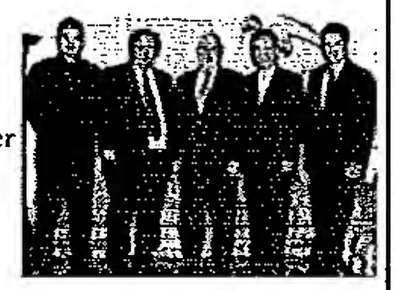
CAS delegation visited ORNL
November 2011



Slide 7

CAS & DOE Exchange Visits & Signing the MOU

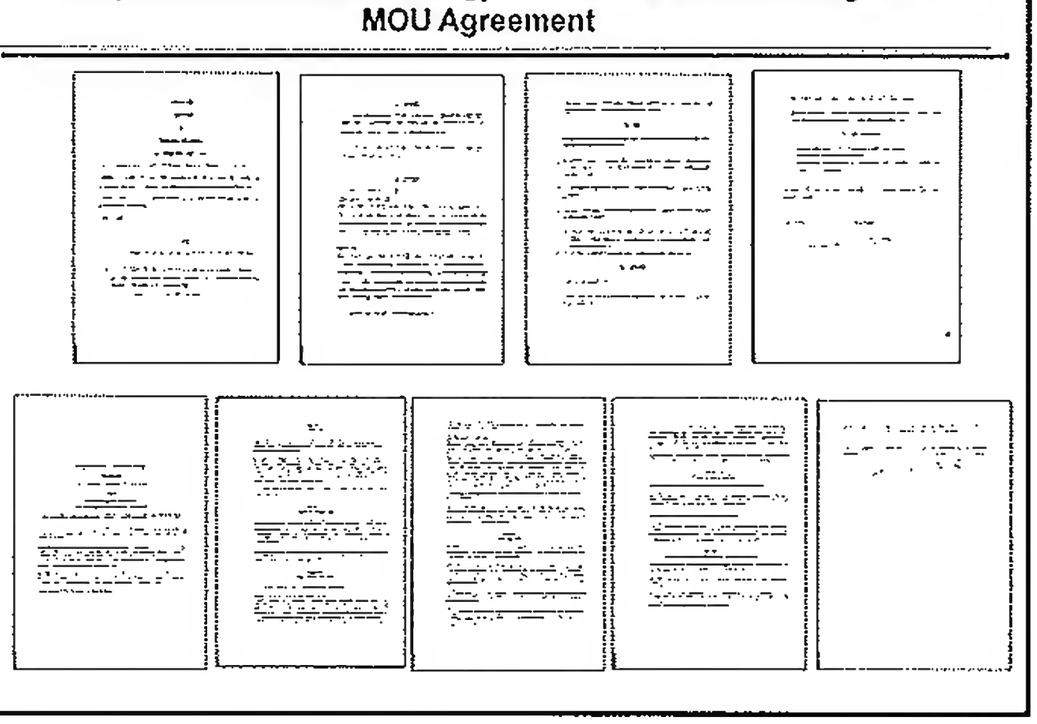
- In August 2011, Stephen Kung, representing US DOE, visited Shanghai to present a draft MOU proposal. The meeting focused on discussion of cooperation mechanism, technical working group scopes, and management structure.
- The MOU agreement on Cooperation in Nuclear Energy Sciences and Technologies was finalized during a CAS follow-up meeting in Washington D.C.



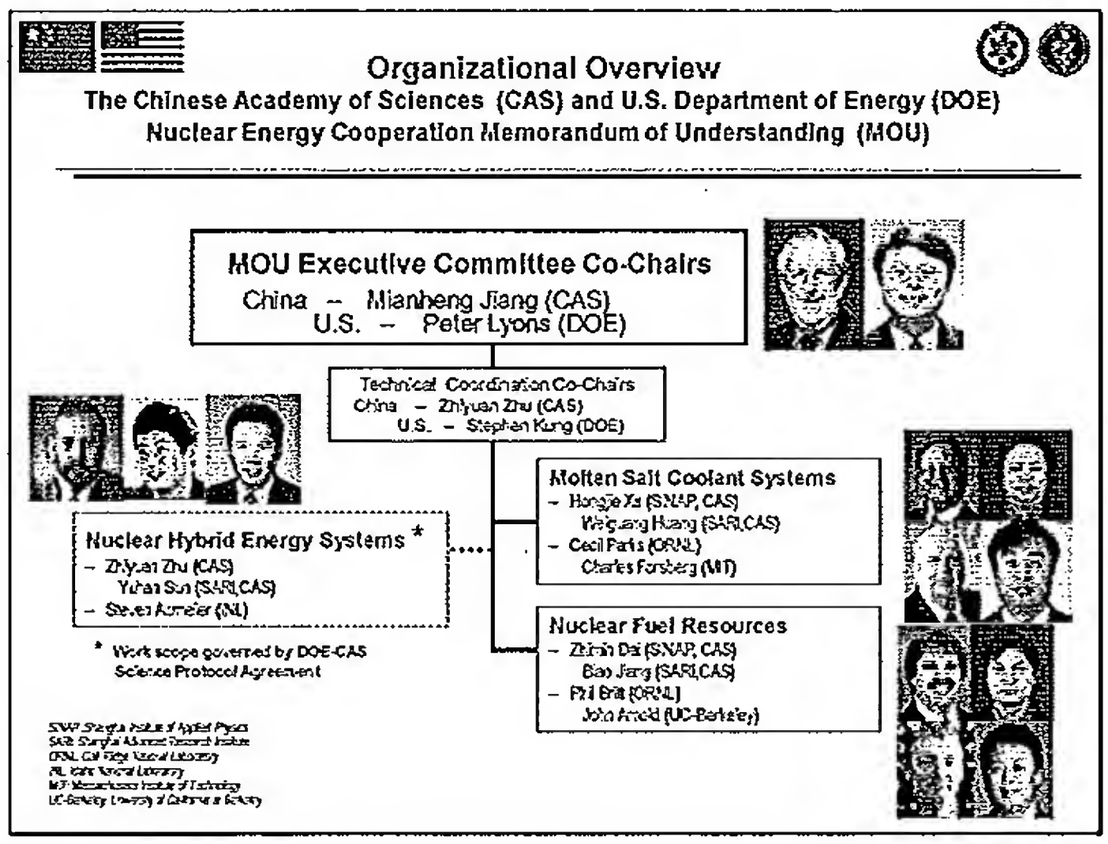
- Drs. Zhiyuan Zhu and Hongjie Xu repersenting CAS met with Dr. John Herczeg, Mr. William Lahneman and Stephen Kung at DOE headquarters on November 4, 2011.
- CAS delegation met with Dr. Peter Lyons, Assistant Secretary for Nuclear Energy, to present the agreed MOU.
- In December 2011, the MOU Agreement was signed by Dr. Peter Lyons and Dr. Jinghai Li representing DOE and CAS, respectively.

Slide 8

CAS-DOE
Cooperation in Nuclear Energy Sciences and Technologies
MOU Agreement



Slide 9

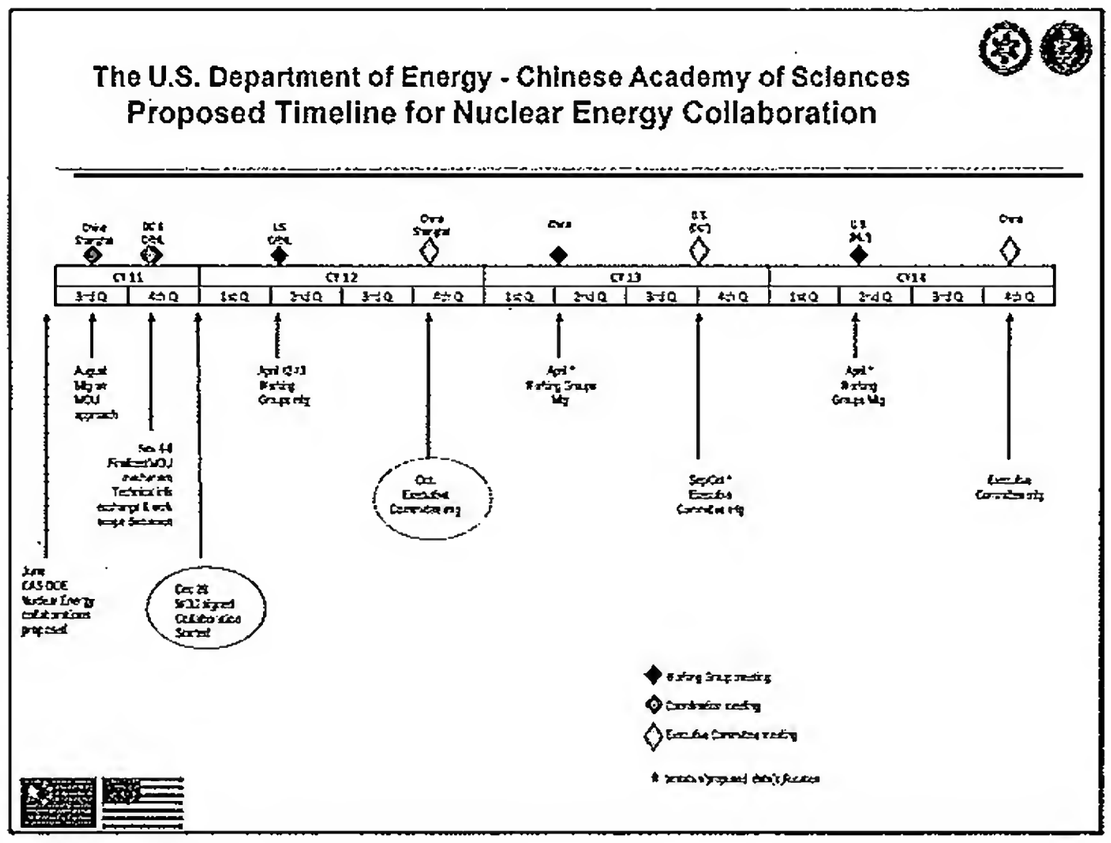


Slide 10

CAS- DOE Nuclear Energy Collaboration
Co-Chairs Responsibilities

- **Executive Committee**
  - Chair annual Executive Committee meeting
  - Review working groups' accomplishments
  - Approve proposed outyear R&D activities
  - Provide guidance on long-term cooperation directions
- **Technical Coordination**
  - Coordinate with working groups to establish implementation plan
  - Propose and identify new collaboration topics and potential opportunities
  - Monitor, facilitate, and assess technical progress of the R&D activities
  - Chair Joint Technical Working Groups meeting, if Executive Committee meeting is not scheduled
- **Working Group**
  - Chair annual Working Group meetings
  - Organize and implement approved collaborative activities
    (e.g., training, workshop, information exchange meeting, perform R&D tasks)
  - Present accomplishments at Executive Committee meetings
  - Document and prepare meeting records and progress reports

Slide 11



Slide 12

One of Content of MOU

Section 3
Areas of Cooperation

1.Priority areas of cooperation may include the following:

Nuclear Energy for Non-electric Applications

Nuclear Fuel Resources

2.The areas of cooperation may be expanded and revised by the written consent of the Participants.

3.The Participants intend to conduct research and development on mutually determined subjects under appropriate written agreements therefor. Such agreements should include, among other matters, provisions for the protection and allocation of intellectual property.

Slide 13

CAS-DOE Nuclear Energy MOU Status and Management

- Executive Committee co-chairs to meet annually to review overall progress and approve future plans.
- Technical coordinators communicate frequently to coordinate and facilitate collaborative activities. E.g., jointly propose and coordinate cooperative activities, and oversee progress of information exchange and working groups meetings.
- Since the MOU was signed, cooperation has been mostly in the forms of working group meetings and discussions, technical information exchanges in open forum, jointly attending review meetings, conferences, and workshops.
- Active interactions among working group co-chairs and researchers are on-going.

Slide 14

Activities under MOU

Meeting and Visits under CAS-DOE MOU in 2012

Date	Interaction	Participants	Note
12.17-21, 2011	Discussion for the research of material corrision property in MSR University of Wisconsin	Todd Allen	
2.20-21	MOU coordination meeting and SINAP tour	Stephen Kung	
3.11-22	Visiting INL and UCB	Li Yan, Yu Xiaohan, Li Zhong, Li Kaye, Zhou Ying	
4.1-9	Attending Hybrid Energy System Workshop	Zhu Zhiyuan	
4.10-18	Visiting ORNL and attending Working Groups Meeting, Visiting UCB and UW for Integrated Research Program	Xu Hongjie, Dai Zhimin, Wu Guobang, Chen Kun, Zhou Xingtai, Xie Leibing	
5.13-18	Attending ASME Code Week	Wu Guanyuan	
6.11	Discussion for Dynamic large scale hybrid energy systems	Robert Cherry	
6.22-30	Attending 2012 American Nuclear Society Annual Meeting and FHR Safety Standard Working Group Meeting, Visiting Ohio State University Nuclear Engineering Program	Dai Zhiming, Xia Xiaoling, Chen Kun, Wang Hong, He Zhaobong	Dai Zhiming selected as FHR Safety Standard Working Group co-chair

Slide 15

Activities under MOU

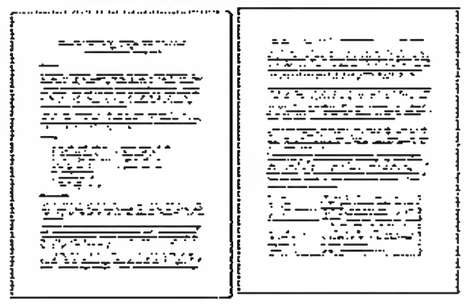
Meeting and Visits under CAS-DOE MOU in 2012			
Date	Interaction	Participants	Note
7.11-13	International Review Meeting for the 2MW TMSR Pre-Conceptual Design and the High Temperature FLiNaK loop design	Jess Gehin, Dane Wilson, Kevin Robb, David Petti, Hu-wen Hu, Guoqing Cao, Ehud Greenspan, Edward D. Blandford	
7.21-27	Attending 5th International Topical Meeting on Nuclear Plant Instrumentation, Control and Human Machine Interface Technologies	Li Yongding, Chen Yongbeng, Huang Guoqing	
8.5-11	Visiting UCB for discussion of MSR licensing, made presentation at dept. colloquium	Chen Kun	
8.17-25	Attending American Chemical Society Meeting Info Exchange Meeting on extraction of uranium from seawater working group	Wu Guozhong, Li Jingye, Wang Members	
8.25-30	Attending 2012 International Pyroprocessing Research Conference (IPRC)	Xu Hongjie, Li Qingyuan, Li Wenfeng, Long Dewu, Zhang Hexuji, Chen Kun	
8.27-9.1	Attending IRP Workshop 3 for the material of FHR application	Xu Hongjie, Zhou Xingtai, Li Zhong, Chen Kun	

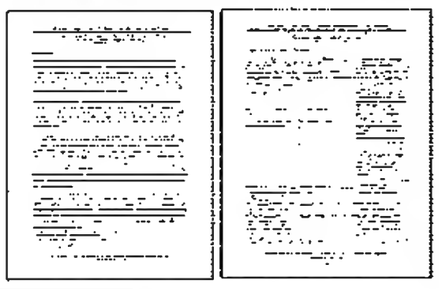
Slide 16

Activities of working groups

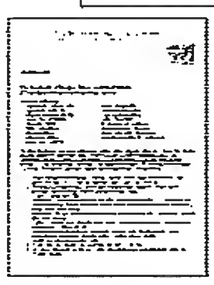
Meeting minutes of the 1st Molten Salt Coolant Working Group Meeting April 2012

Minutes of Phase I Work Statement on Nuclear Hybrid Energy Systems Aug. 7, 2012 video conference

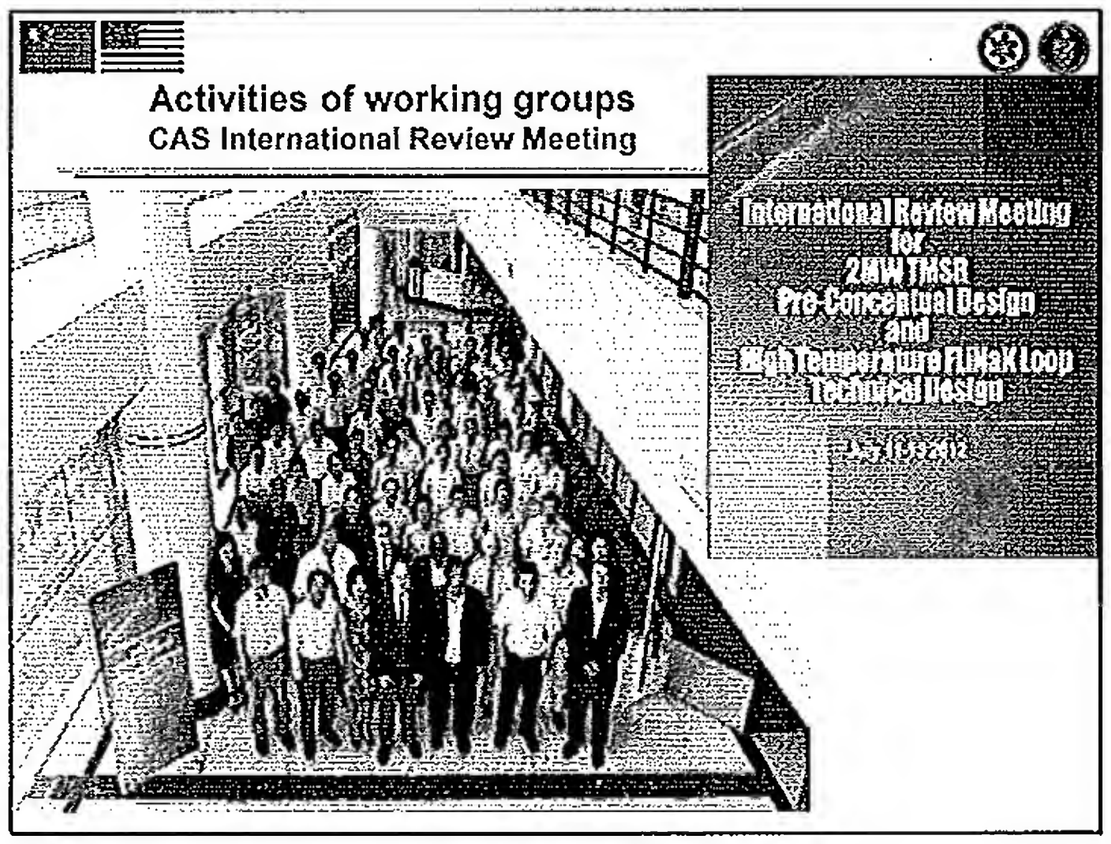




Fuel Resources
Meeting Minutes
April 2012
&
Sept. 2012



Slide 17



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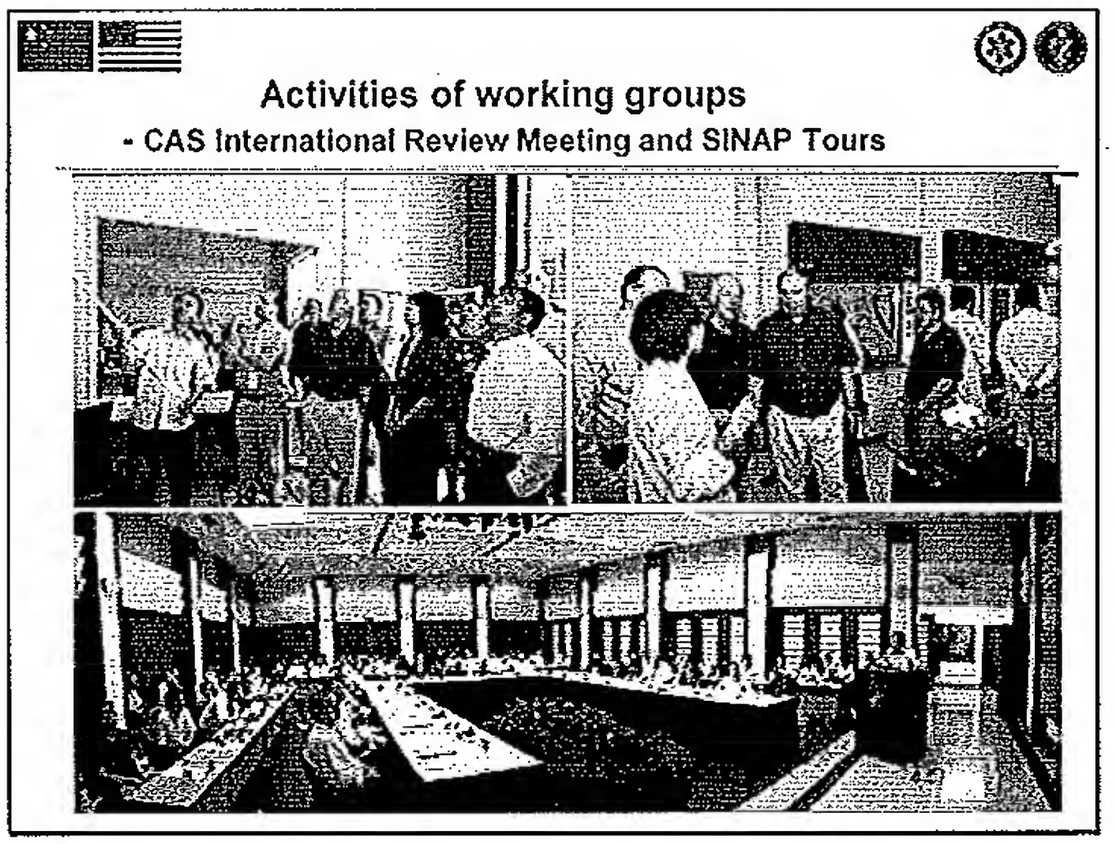


Slide 19

Summary

- **Nuclear Energy Sciences and Technologies Cooperation MOU Agreement between CAS and DOE was signed in December 2011.**
- **Three Working Groups were established:**
  - Molten Salt Coolant Systems
  - Fuel Resources
  - Nuclear Hybrid Energy Systems
- **Active collaborations of the three working groups are progressing well.**
- **Potential new topical areas will continue to be explored.**
- **Executive Committee guidance and approval will inform future collaborative directions and activities.**

Slide 20

Thanks for your support of the CAS-DOE nuclear energy cooperation.

Attachment F:

Molten Salt Coolant System Working Groups Meeting Presentation and Planned Future Activities

Slide 1

Molten Salt Cooling System Working Group Progress & Future Plan

Hongjie Xu
2012-10-22, Shanghaji

中国科学院上海应用物理研究所
Shanghai Institute of Applied Physics, Chinese Academy of Sciences

Slide 2

OUTLINE

New Plans on TMSR Project

FHR Research Activities in USA

Progress for the collaboration

Collaboration Proposal Next Year

Slide 3

OUTLINE

New Plans on TMSR Project

[illegible]

Slide 4

New Plans of TMSR Project

- **CAS has just approved the new plans of TMSR project, which includes two parts:**
  - Build two experimental reactors (TMSRs) and the non-electric application experimental facilities.
  - Build up R&D abilities (include research conditions, key technolegy and research team etc.) for future TMSR deveopment.
- **CAS has started the approving procedure to combine the research program "Uranium recover from Seawater" into TMSR project.**

Slide 5

Experimental reactors and the non-electric application experimental facilities

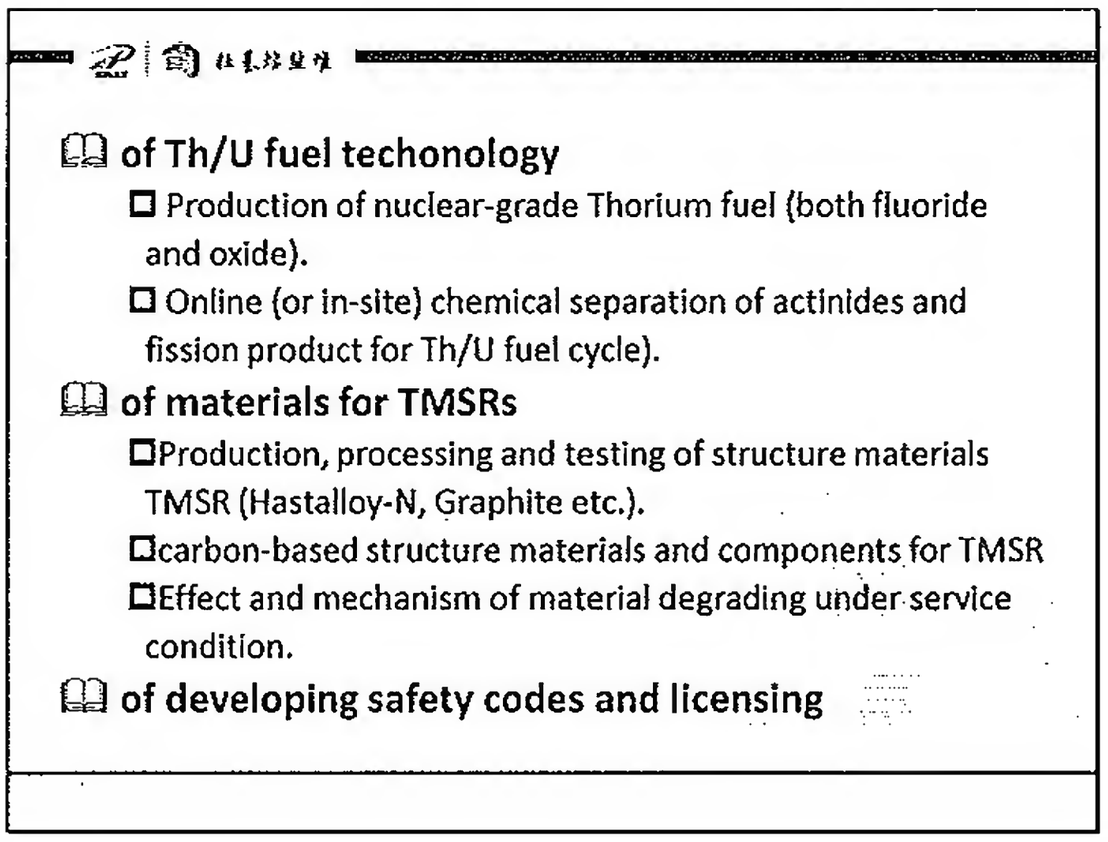
- 2MW Pebble-bed Fluoride Salt Cooled Reactor (with Thorium-Uranium alternate once-through fuel cycle, ~2017)
- 2MW Molten Salt Reactor (with Thorium-Uranium *modified Open Fuel Cycle, ~2020))*
- 100kW SOEC experimental facility (2015)
- 1kg/h methanol reactor (H_2+CO_2) experimental facility (2015)
- 100kW CSP (the salt is absorber and heat storage media, 2015)

Slide 6

R&D abilities for future TMSR deveopment

- **of TMSR reactor design and development.**
  - Reactor core design: neutron physics, thermal hydraulics...
  - Engineering design and construction.
  - Key technologies and components.
- **of salt product technology and molten salt loop technology.**
  - Separation of ^{7}Li.
  - Purification of fluoride salt.
  - Design and construction of molten salt loops.
  - Development of key components for molten salt loop.

Slide 7



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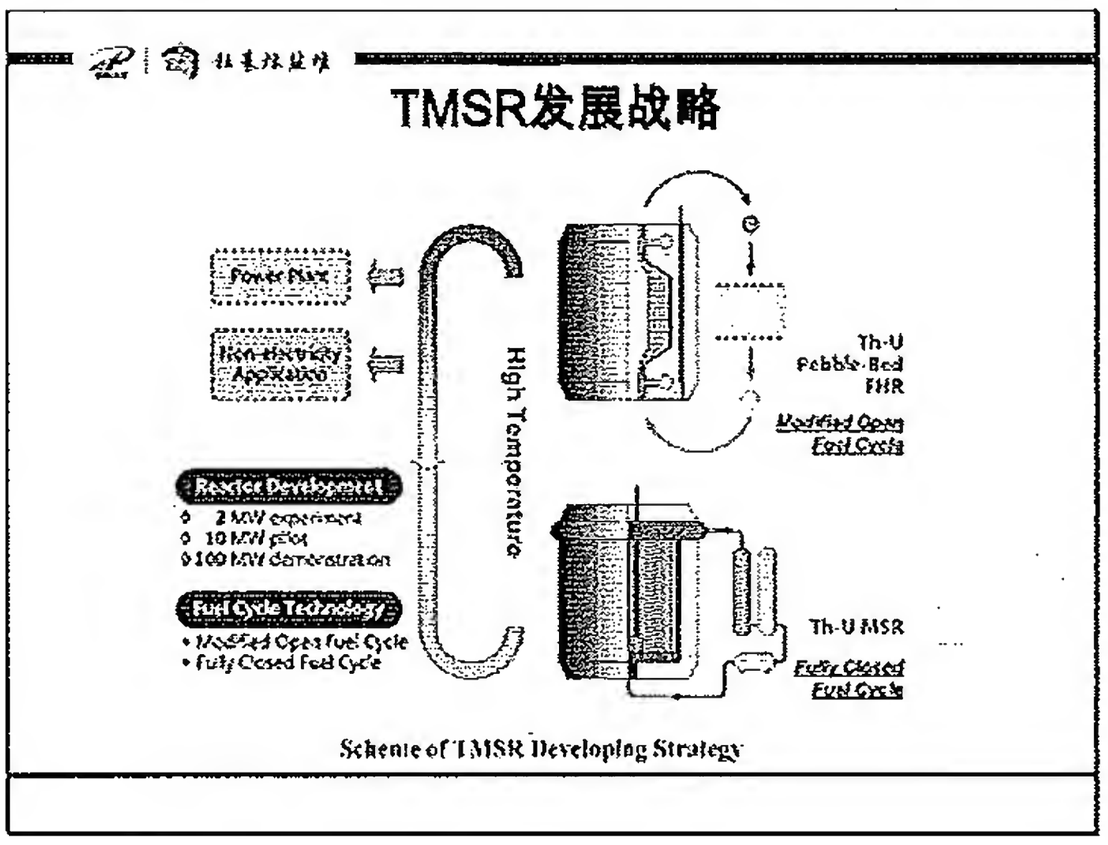

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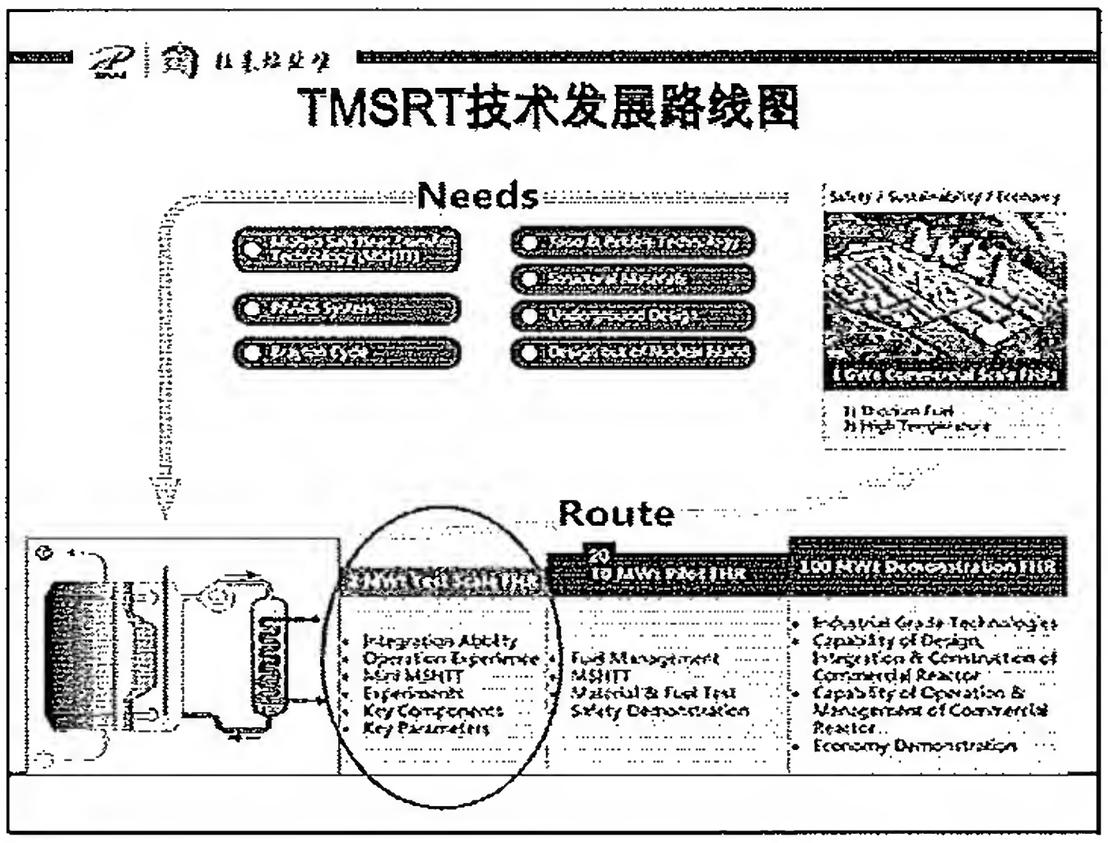

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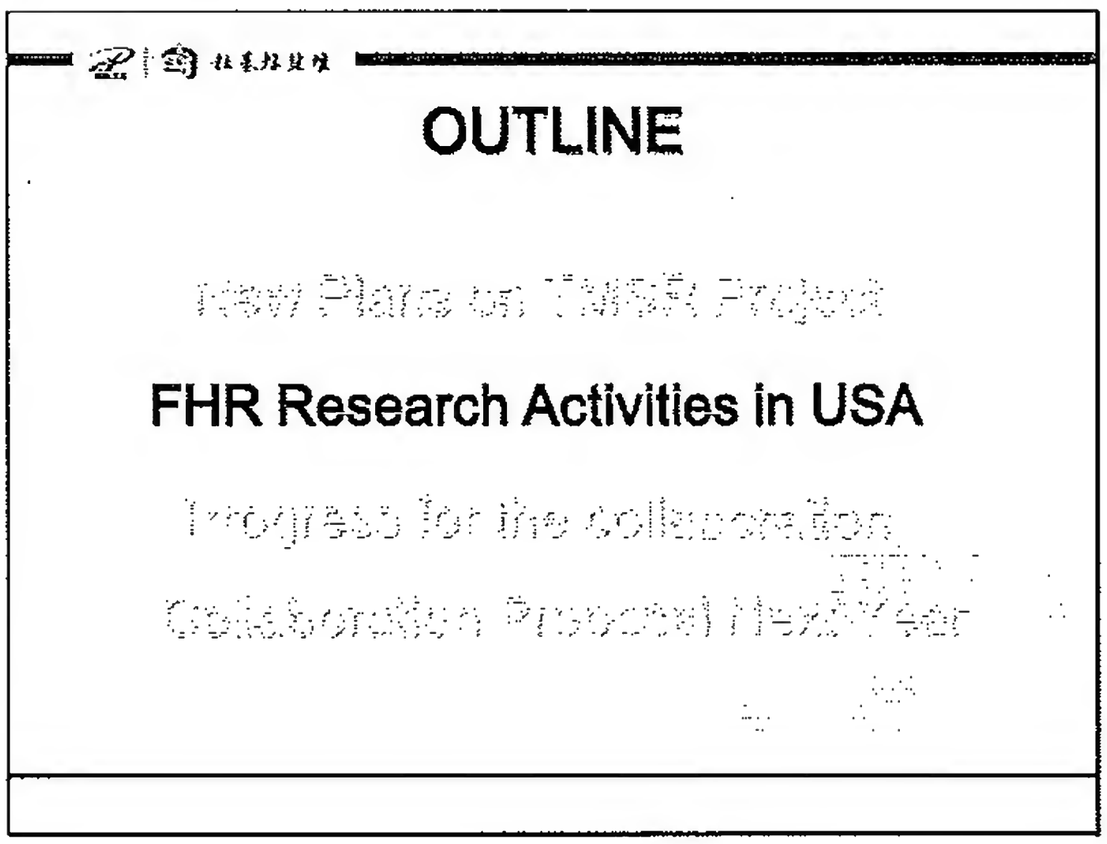
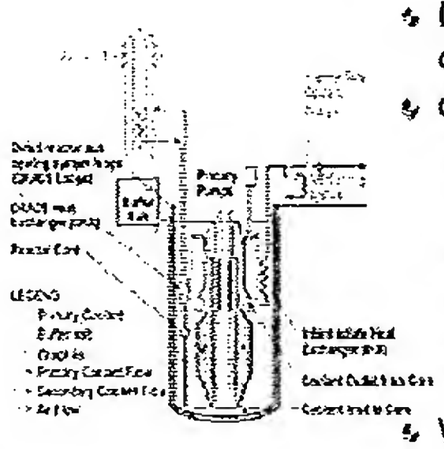


Slide 11

Integrated Research Project MIT,UCB,UW

Fluoride Salt-Cooled High-Temperature Reactor (FHR) Project

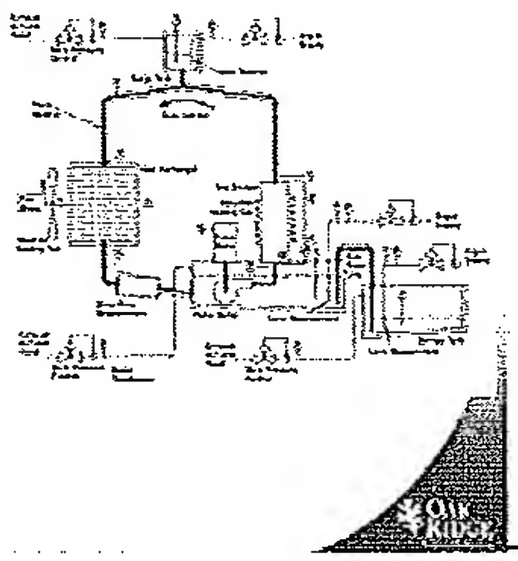


- Develop a path forward to a commercially viable FHR
- Goals
  - Superior economics (30% less expensive than LWR)
  - Limit severe accidents
  - 700° C for higher thermal efficiency and process heat
  - Better non-proliferation and waste characteristics
- Westinghouse advisory role
- Start January 2012

Slide 12

The Forced Convection Loop Incorporates Inductively Heated Pebble Test Section

- Storage Tank
- Pump sump
- SiC test section (pebble channel)
- 200 kW inductive heating
- Forced draft air cooler
- Trace heating system
- Major measurements



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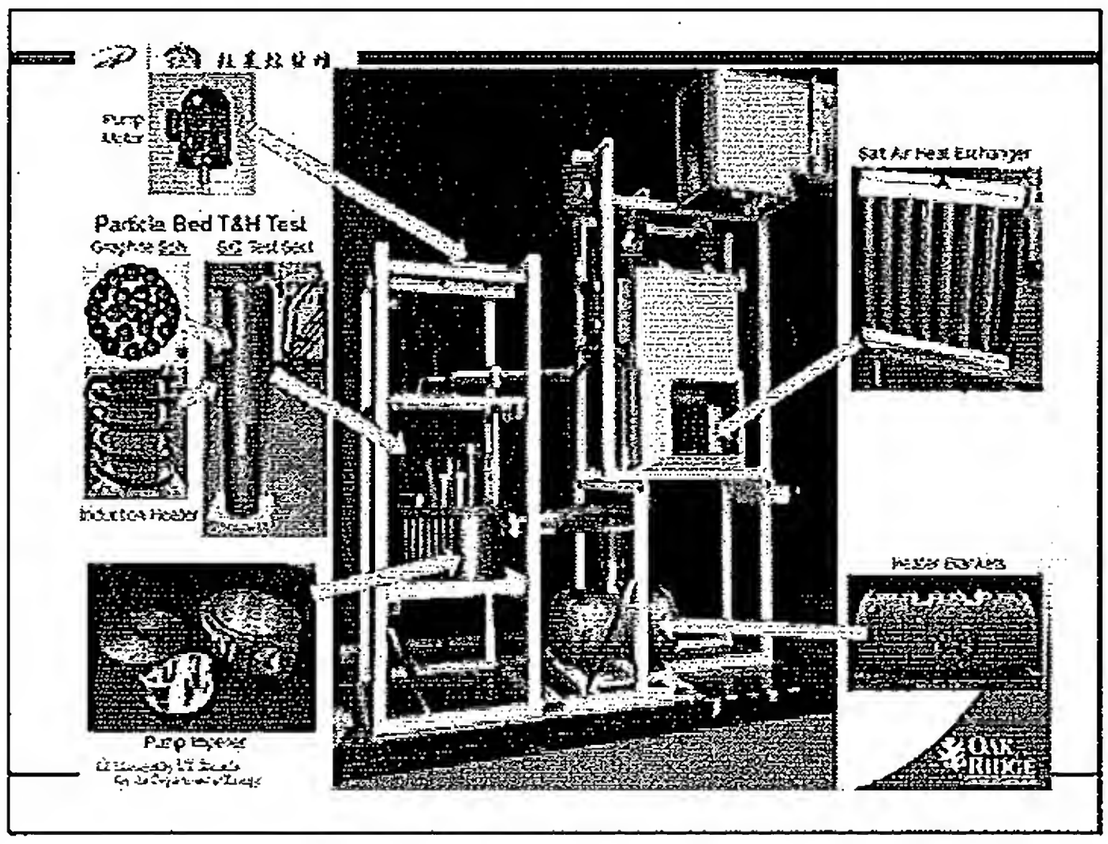

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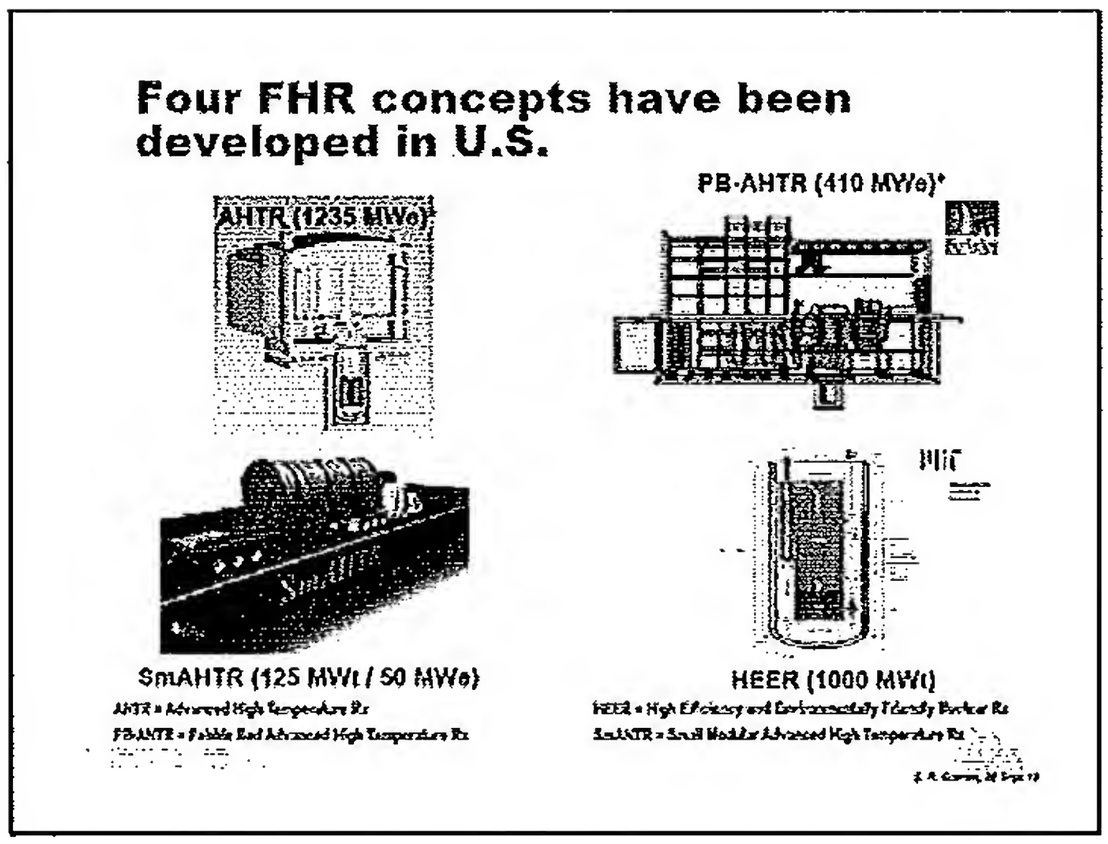


Slide 15

OUTLINE

New Plans on TMSR Project

FHR Research Activities in USA

Progress for the collaboration

Collaboration Proposal Next Year

Slide 16

Collaboration Activities - I

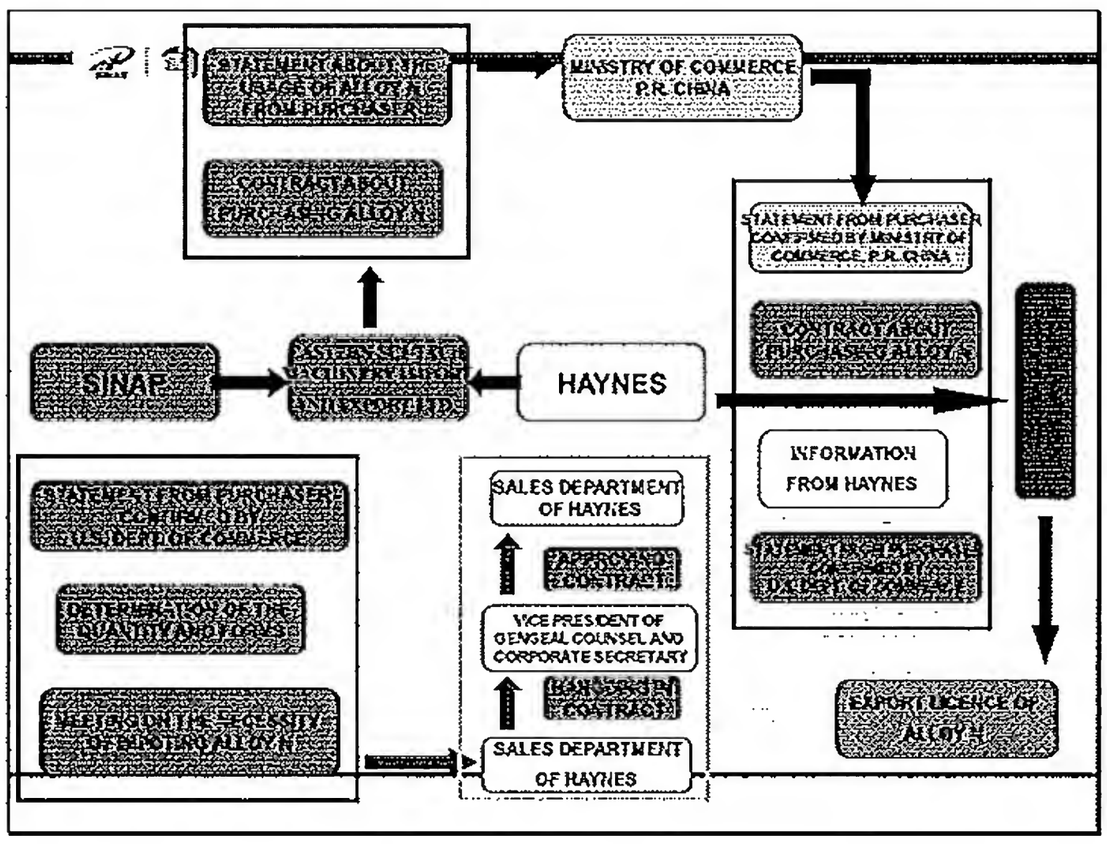
- 1st Working Group Meeting of DOE/CAS Cooperation in NEST ORNL - April 12-13, 2012
- Summary of Meeting Actions With Regard to Salt Reactors
- Procurement of Hastelloy-N metal
- May 23-24 GIF MSR meeting at OECD Headquarters in Paris; Dr. Hongle Xu and Dr. Zhimin Dai will serve as observers.
- June 24th 7:30PM Haymarket Room; Hyatt Regency Chicago; Organizing meeting for FHR safety standard
- July 11-13 2MW TMSR Pre-Conceptual Design and High Temperature FLiNak Loop Technical Design

Slide 17

Collaboration Activities - II

- August 26—29 , International Pyroprocessing Research Conference (IPRC) ,Fontana, Wisconsin. (6 attended)
- August 29-30; University IRP FHR Materials Workshop; Dr. Todd Allen (allen@engr.wisc.edu) host (4 chinese scientist attended)
- October 22-26 DOE-NE Executive committee meeting, visit to SINAP and Sanmen.
- October 31st - November 1st FHR test reactor planning meeting MIT; Dr. Lin-wen Hu (lwhu@mit.edu) host.(5 will attend).
- Nov.5-6日 , Symposium on the MS Hydronics will be held in UCB (about 10 will attend)

Slide 18

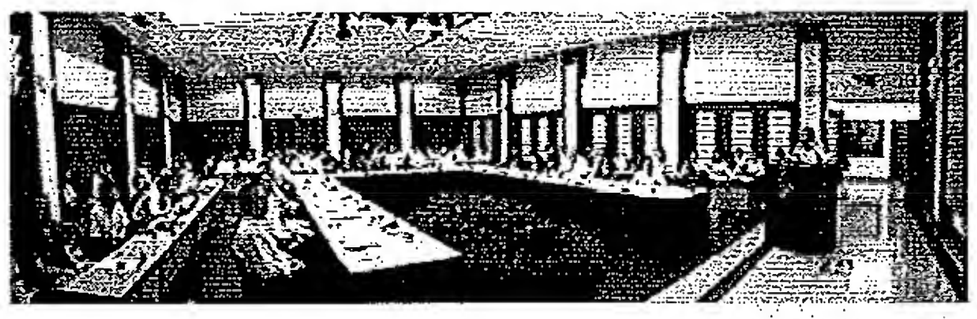


Slide 19

会议概述

- July 11-13 ;
- Jiading Campus of SINAP ;
- 7 presentation of Chinese side.
  9 presentation from review commite
- More than 100 staffs of TMSR attended the meeting.

Slide 20



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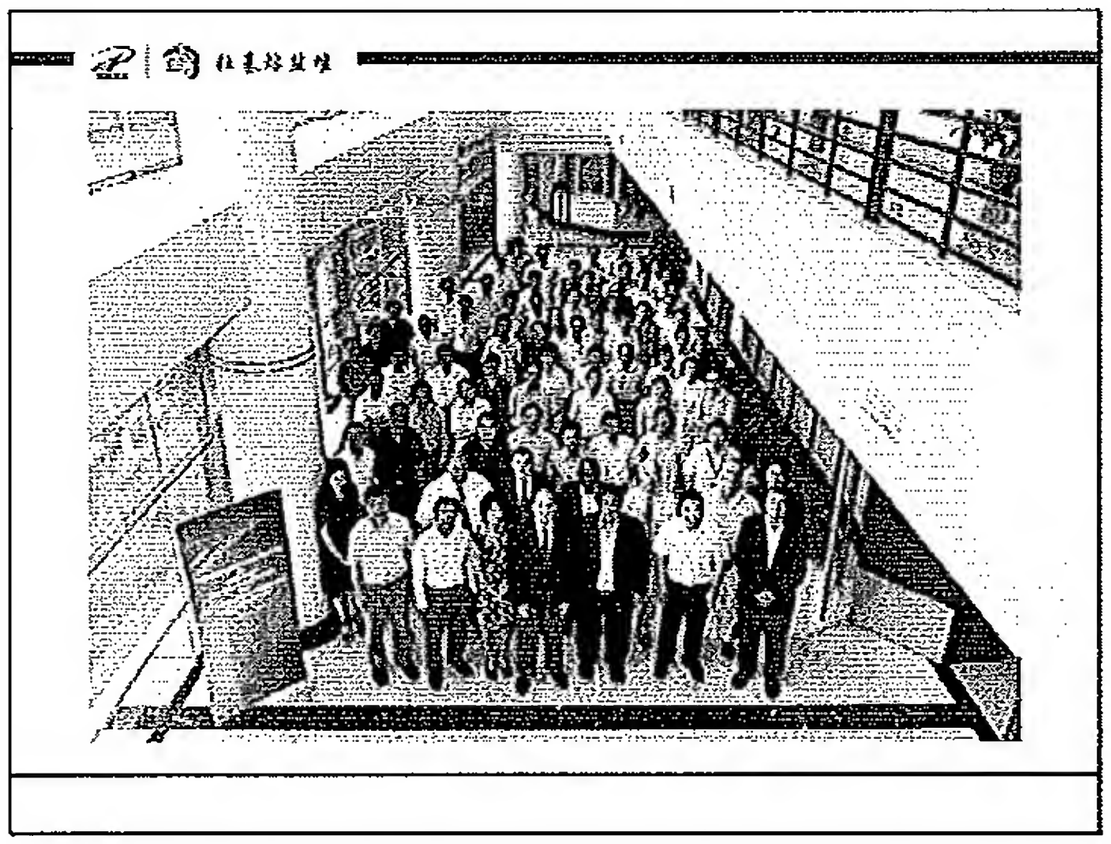

Slide 22

2MW TMSR Pre-Conceptual Design and The High Temperature FLiNaK Loop Technical Design Review Committee Report

International Review Committee:
Dr. Edward Blandford, University of California, Berkeley
Dr. Guoping Cao, University of Wisconsin – Madison
Dr. Jess Gehin, Oak Ridge National Laboratory
Dr. Ehud Greenspan, University of California, Berkeley
Dr. Un-wen Ho, Massachusetts Institute of Technology
Dr. Victor Ignatiev, Russian Research Center "Kurchatov Institute"
Dr. David Petti, Idaho National Laboratory
Dr. Kevin Robb, Oak Ridge National Laboratory
Dr. Dane Wilson, Oak Ridge National Laboratory

October 2012

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Slide 23

FHR Materials and components Workshop

FHR Workshop - 3 (29-30 Aug. 2012)

- University of Wisconsin-Madison
- Topics focus on the material (Fuel Fabrication and performance, Ceramic and Ceramic Composite Components, Metallic Components, Salt Corrosion and Chemistry Control, Preliminary FHR Fuel and Materials Test Program)
- Per Peterson (UCB)、Charles Forsberg (MIT)、Todd Allen (UW-Madison)、Regis Matzie (Westinghouse)、Jess Gehin (ORNL)、Carl M. Stoots (INL)、Jim Nestell (MPR Associates)、Victor Ignatiev (Rusia) 、Zbysek Novy (Czech) ; Hongjie Xu, , Xingtai Zhou, Zhong Li, Kun Chen and others

2013-1-9 23

Slide 24

OUTLINE

New Plans on TMSR Project

R&D Program Activities in USA

Progress for the collaboration

Collaboration Proposal Next Year

Slide 25

Future Plan

- Item Molten Salt Cooling System change to FHRs, which will include:
  - Design and modeling of molten salt cooled reactors, which may include neutronic and thermal hydraulic analyses, thermal hydraulic experiments, design and tests of passive decay heat removal systems.
  - Licensing of design software owned by DOE such as MCNP, SCALE and RELAP5-3D with molten salt coolant module.
  - Molten salt loops technologies, such as pumps, heat exchangers, connects and instruments, control of tritium in molten salt system such as study of tritium behavior in molten salt, tritium detection and removal, tritium storage materials, and production of 7Li enriched

Slide 26

Future Plan

- Materials used for molten salt cooled reactors, such as development of TRISO fuel for molten salt cooled reactors, material corrosion studies, irradiation studies of materials in high temperature molten salt, procurement of Hastelloy-N metal, 316-SS research and development of carbon based materials.
- Pyroprocessing Research collaboration (used for TMSR).

- To hold series bilateral workshop and seminer (such as IRP workshops), and Chinese side will continue invit american scientists to have technique review.
- Open experimental facilities reciprocally.
- More Personal exchanging

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Slide 1

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

US Report on Collaboration Activities for the Working Group on Molten Salt Coolant Systems

Executive Committee Meeting for DOE – CAS Cooperation in Nuclear Energy Sciences and Technologies

22 October 2012
Shanghai, China

FHR
Fluoride Salt Cooled High Temperature Reactor

Presented by:
Cecil Parks and Charles Forsberg,
US Leads for Working Group on Molten Salt Coolant Systems

Slide 2

Outline

- Brief review of DOE-NE programs for molten salt coolant systems
- Review of 2012 collaboration activities
- Proposed collaboration activities for 2013
- Potential collaboration activities beyond 2013

FHR
Fluoride Salt Cooled High Temperature Reactor

Fluoride Salt Coolant High Temperature Reactor (FHR) Concept and Technology Development are Focus of US R&D Efforts on Molten Salt Coolant Systems

- DOE directing national laboratory and university R&D

October 2012 2

Slide 3

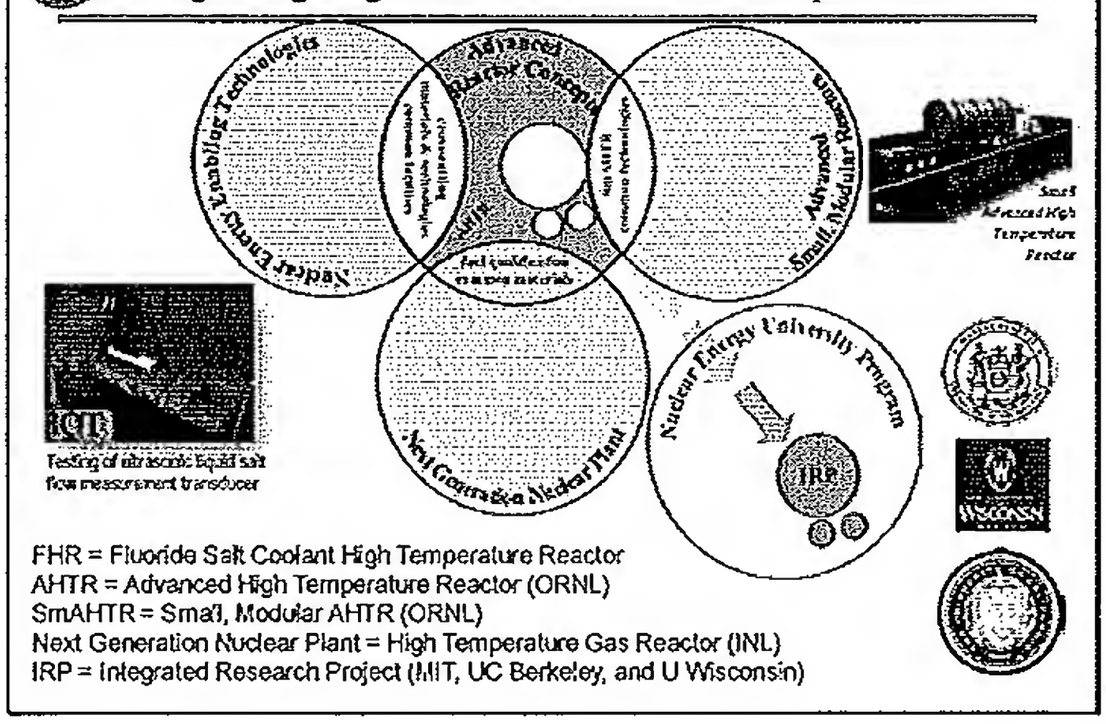
The FHR is in a Different Reactor Design Space

Coolant Temperature	System Pressure: Low	System Pressure: High
Low		Light-Water Reactor
Medium	Sodium Fast Reactor	
High	FHR	High-Temperature Gas-Cooled Reactor

Creates Challenges and Incentives for Cooperation

Slide 4

DOE Advanced Reactor Concepts Program is the US Integrating Organization for FHR Development

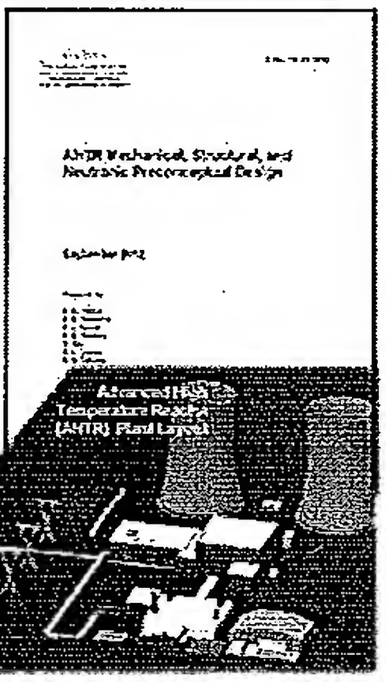


FHR = Fluoride Salt Coolant High Temperature Reactor
AHTR = Advanced High Temperature Reactor (ORNL)
SmAHTR = Small, Modular AHTR (ORNL)
Next Generation Nuclear Plant = High Temperature Gas Reactor (INL)
IRP = Integrated Research Project (MIT, UC Berkeley, and U Wisconsin)

Slide 5

FHR Concept and Technology Development are Focus of US Efforts on Molten Salt Coolant Systems

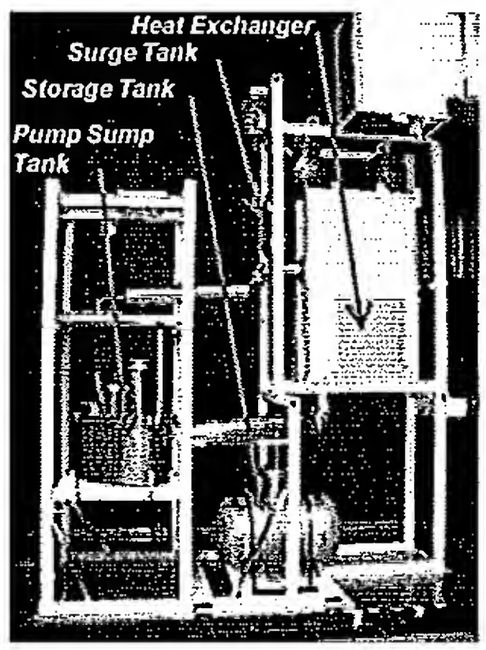
- Identify unresolved R&D needs and challenges
  - Extensive historical experience used as initial basis
- Emphasis on leveraging passive safety characteristics to reduce plant costs, shorten development timeframe, and enable licensing
- FHR technology maturity evaluation and development roadmap will be produced in 2013
- Current FHR technology areas
  - Safety and licensing (e.g., standards, accident identification, tritium management)
  - Component development and testing (e.g., fluidic diodes)
  - Advanced alloy testing and evaluation
  - System performance modeling
  - Instrument development
- Test reactor concept development



Furnace testing of high-temperature fission chamber

Slide 6

Versatile Liquid Salt Loop Has Been Constructed at ORNL To Test High Temperature Salt Components



- Experimental facility will include a salt purification system designed to remove moisture and oxides in the salt to minimize corrosion
- A fluidic diode (a leaky check valve with no moving parts) will be tested early in the experimental program
  - Key decay heat removal component

- Follow on testing will focus on scaled AHTR components such as:
  - Fuel heat transfer testing
  - Improved pump designs
  - Salt-to-salt or salt-to-gas heat exchanger
  - Instrumentation
  - Refueling components

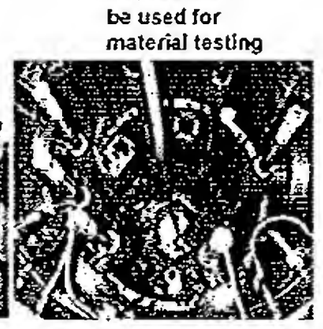
Slide 7

DOE Integrated Research Project (IRP) Is Working To Advance FHR Technologies In Key Areas

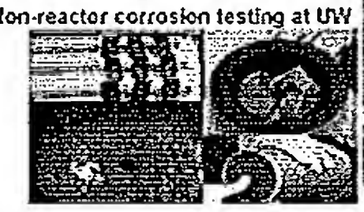
- System and subsystem function and evaluation
- Design and licensing issues
  - Thermal hydraulics and safety tests at UC-B
- Material and component selection and performance (UW)
- Coolant/material tests in MIT research reactor
- FHR test reactor functional requirements and pre-conceptual design (MIT)
- Commercial reactor conceptual design (UC-B)
- Developing potential commercialization strategies linked to specific strengths of molten salt systems (MIT)

UC-B thermal loop uses molten salt simulant

MIT reactor to be used for material testing



Non-reactor corrosion testing at UW

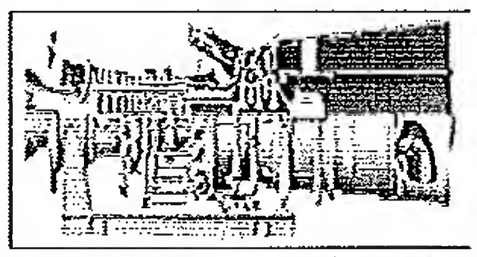


IRP reactor concepts based on pebble-bed fuel

Slide 8

IRP Investigating Potential for FHR to Open New Markets for Nuclear Power via Use of Brayton Cycle

- Potential capabilities
  - Base-load electricity
  - Peak electricity
  - Grid regulation
  - Process steam production
- May enable nuclear renewable electricity system
- Cross over with hybrid energy systems



Open-air Brayton Combined Cycle could enable use of natural gas to support peak power and grid regulation

Slide 9

There are Multiple Universities Engaged in FHR Research and Development

University	Technical Areas
MIT U. of California U. of Wisconsin	Integrated Research Project
Georgia Institute of Technology	Core Design
Ohio State University	Decay Heat Removal
John Hopkins University	Carbide Coatings for Salt Systems
U. of New Mexico	Safety, Heat Transfer

Slide 10

2012 Activities Coordinated by Working Group

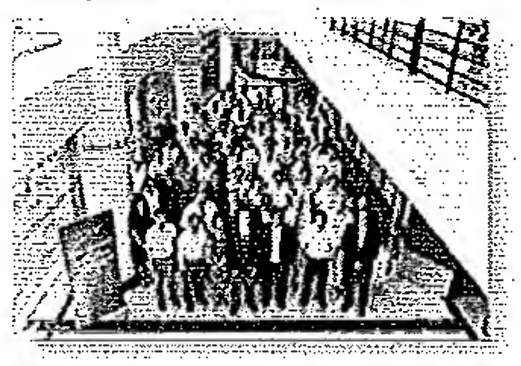
- **Visit by CAS to ORNL April 12 - 13 (1st Working Group Meeting)**
  - Tours of ORNL liquid salt test loop and materials R&D facilities
  - Update provided on status and progress of CAS Thorium Molten Salt Reactor (TMSR) program
  - Discuss potential collaboration activities and process
  - Plan short-term collaboration activities
- **Initiation of American Nuclear Society Safety Standard on FHRs**
  - Organizing meeting held in June
    - *Co-chaired by US (Ed Blandford and Matt Denman) and China (Zhimin Dai)*
    - *Representatives from US and Chinese nuclear safety authorities participating*
  - First writing meeting scheduled for November preceding ANS meeting
- **DOE & CAS participating in GIF MSR system steering committee**
  - May meeting: OECD in Paris (David Holcomb, Hongjie Xu, and Zhimin Dai)
  - National programs described to international audience
  - Potential for GIF bilateral reactor technology collaboration discussed
  - November meeting at ITU in Karlsruhe Germany

October 2012 10

Slide 11

2012 Activities Coordinated by Working Group

- **Chinese participation in DOE Integrated Research Project workshops on FHRs**
  - 29 – 31 August at UW: Materials and components
  - 1-2 November at MIT: Test reactor requirements
- **July: Shanghai Institute of Applied Physics hosted international review of TMSR program**
  - US Participants
    - *Jess Gehin, Chair (ORNL)*
    - *Dane Wilson (ORNL)*
    - *Kevin Robb (ORNL)*
    - *David Petti (INL)*
    - *Lin-wen Hu (MIT)*
    - *Ed Blandford (Stanford)*
    - *Gouping Cao (Wisconsin)*
    - *Ehud Greenspan (UC-B)*



- **ORNL provided Haynes International with background information for CAS procurement of Hastelloy N**

Slide 12

2012 Activities Coordinated by Working Group

- **Confirmation of additional design parametric study**
  - UC Berkeley developed models to confirm criticality and reactivity feedback mechanisms for the solid fuel TMSR baseline design provided by CAS. Results discussed at review meeting held in July.
- **Lithium enrichment studies**
  - After learning of SINAP challenges with identifying a supplier of Li enriched to ^{7}Li purities greater than 99.95%, UC Berkeley did a study to identify the impacts on the coolant reactivity feedback and estimated the minimum lithium purity requirements. This study concluded that an ^{7}Li purity of 99.99 was required to maintain criticality and negative temperature reactivity coefficients. Results shared with SINAP.
- **Fnabe coolant studies**
  - Following up on the lithium enrichment studies, UC Berkeley did a scoping study to assess the feasibility of designing a test reactor cooled with fnabe rather than flibe with 99.95% ^{7}Li. This study concluded that it is feasible to design a fnabe cooled test reactor with negative coolant temperature reactivity coefficients.

Slide 13

Proposed 2013 Collaboration Activities

- **Information exchange and/or focused workshops on key safety and technology issues**
  - FHR tritium management
  - Assessment of FHR accident initiators
  - Molten salt pump development and design
  - IRP-sponsored workshops
  - Salt compatibility testing of materials and components – techniques and needs

Molten salt loop at ORNL

- **Joint participation in safety standards**
  - ANS FHR safety standard
  - ASME Committee on Materials for High Temperature Liquid-Cooled Reactors
- **Joint evaluation and initial collaboration plan for**
  - FHR hydraulic design and testing tools
  - Experiment and model validation needs
  - Experiment data that can be shared

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October 2012

Slide 14

Proposed 2013 Collaboration Activities

- **Student exchange internships via the IRP universities**
- **Explore opportunities to review and advise on TMSR technical program, as requested by CAS**
- **Explore options for CAS use of US safety-related software**
- **Explore opportunities for sharing information on chemistry of rare earth and actinide halides in molten salt and actinide/lanthanide concentration measurement techniques in molten salt**

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October 2012

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Nuclear Energy

Questions

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Attachment G:

Fuel Resources Working Group Meeting Presentation and Planned Future Activities

Slide 1

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Fuel Cycle Research and Development

Uranium from Seawater

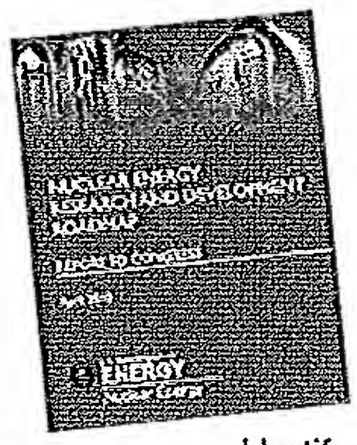
Phillip Britt
Oak Ridge National Laboratory

Executive Committee Meeting
October 22, 2012

Slide 2

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Fuel Resources



"Fuel Resource Exploration and Mining – The availability of fuel resources for each potential fuel cycle and reactor deployment scenario must be understood... involvement in this area would be R&D to support investigation of long-term, 'game-changing' approaches such as recovering uranium from seawater."

Fuel Resources Mission

Identify and implement actions to assure that economic nuclear fuel resources remain available in the United States

2

Slide 3

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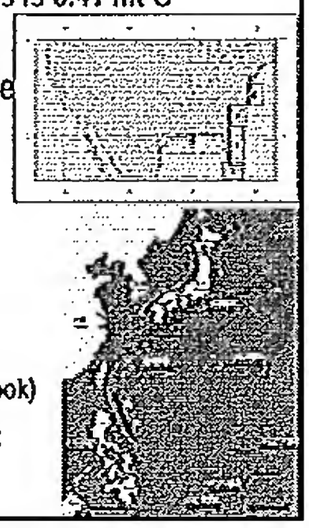
Why Uranium from Seawater?

- Seawater has approximately 10,000-times more uranium than conventional U.S. terrestrial resource and it is a local resource
  - Estimated 4,500 Mt U in seawater while U.S. reserves is 0.47 Mt U
- Seawater uranium would provide a price cap and provide centuries of uranium even with aggressive world-wide growth
- Challenge is low concentration: 3.3 ppb
  - Approximately 300,000 t seawater for 1 kg U
    - Black Current off Japan carries 5.2 Mt U/year
- World-wide estimates of terrestrial uranium resources at a cost less than $260 kg/U (2009 Red Book)
  - Conventional and undiscovered uranium resource: 12.9 Mt U



Slide 4

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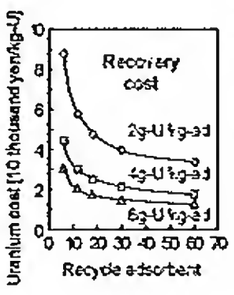
Previous Research on Extraction of Uranium from Seawater

- Research efforts started in the late 1950's in the United Kingdom
- World wide studies followed (especially in 1970-1980's) from Japan, Germany, Italy, France, China, and United States that evaluated solvent extraction, inorganic adsorbents, polymeric adsorbents, biomass collection, etc.
- Early focus on hydrous titanium oxide (TiO_2) but low capacity, poor stability of adsorbent and high cost of pumping the seawater
- In the 1980's, amidoxime-based polymeric adsorbents became the focus based on lab and field scale research from Germany
- In 1990-2000's, Japan has lead the way in uranium extraction from seawater with amidoxime-based adsorbent



Slide 5

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Fuel Resources Workshop Report
- Fuel Resources R&D Roadmap

Workshop Co-chairs:
Charles W. Forsberg, MIT
J. Stephen Herring, INL
Philip F. Britt, ORNL

Workshop Charge: To evaluate the scientifically challenging and emerging research areas that have the potential to significantly impact technology development needs to ensure the availability of uranium resources for global nuclear expansion. The workshop output is a report that will outline research opportunities for future fuel resource technologies with a focus on recovery of uranium from seawater.

Plenary Speakers:
Jan Slezak*, IAEA, U Resource Estimation Red Book perspective
Bob Vance*, OECD, Projected Global Build Rates and U Demand
T. Shimizu, JAEA, Seawater U Extraction

"To make the collection of uranium from seawater more economically competitive, the workshop identified five future research directions: (1) molecular-level understanding of the coordination modes, sorption mechanisms, and kinetics of uranium extraction; (2) design and synthesis of functional ligands; (3) development of advanced sorbents (high-surface area polymer and hybrid supports); (4) development of new polymer sorbents via surface grafting techniques; and (5) development of innovative elution processes."

5

www.osti.gov/scitech/nuclearfuel/resources/testdocs/overview/NE_Workshop_Report_Oct2010.pdf

Slide 6

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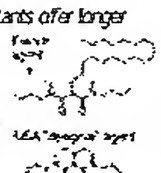
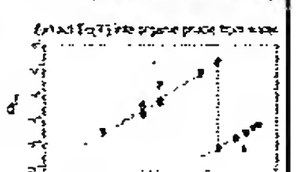
Fuel Resources R&D Strategy: Developing Advanced Adsorbents

- Increase sorption capacity
  - Surface area *(reduce the fiber size and/or change the fiber shape)*
  - Functional group density *(tailored nanostructure design and nanomanufacturing)*
  - Grafting efficiency *(radiation with gamma, X-ray, e-beam, UV-Vis, chemical methods)*
- Sorption of competing species in seawater environment
  - Improve adsorbent selectivity through enhanced ligand design *(high performance computing & modeling, hard/soft donors, stereochemistry)*
- Enhance adsorbent durability
  - Increase the structural integrity of backbone or trunk materials
- Improve U stripping methodology
  - Carbonate solution, supercritical carbon dioxide *(better U eluants offer longer adsorbent lifetimes and less costly and "greener" processing)*
- Sorption mechanism and thermodynamics
  - Advanced characterization tools to increase understanding
- Inhibition of biofouling/scale formation
  - Coatings *(surface sol-gel process)*
  - Specialized polymer compositions and nanoporous adsorbents

20 um diameter fiber shaped vs. round fiber - 60% increase SA

Computer-aided molecular design





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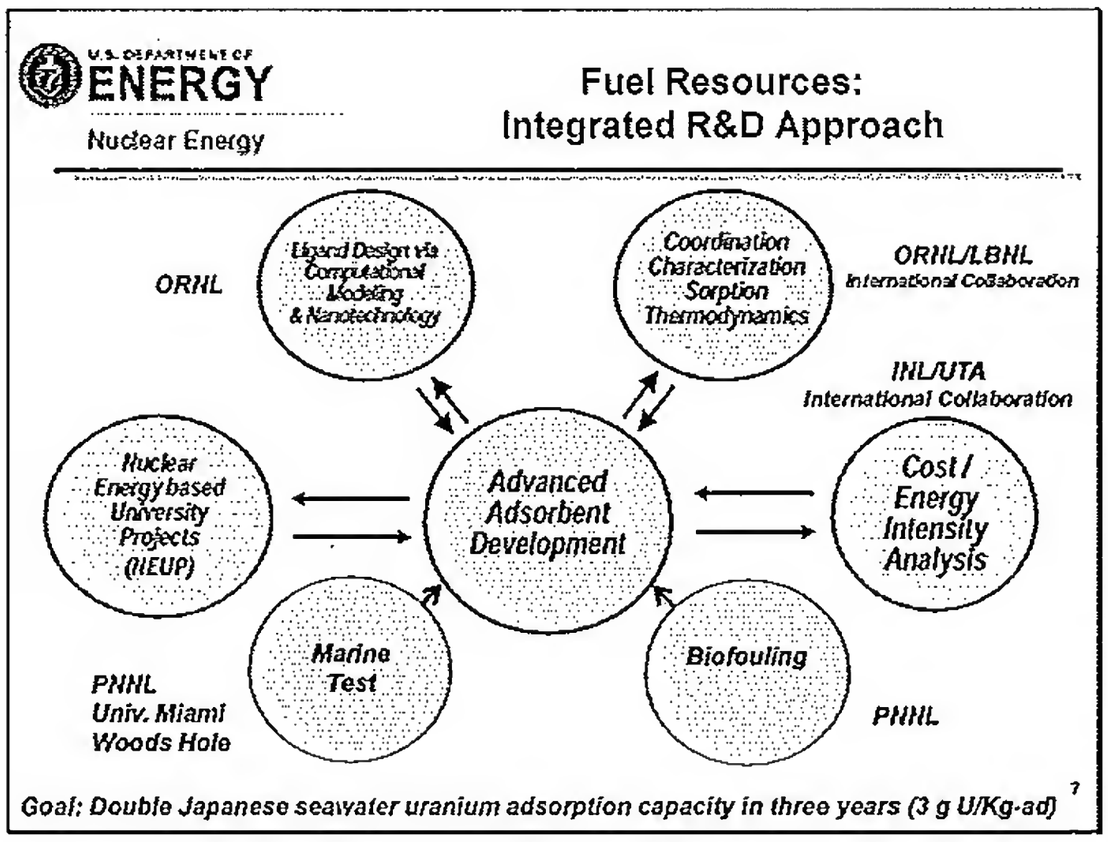

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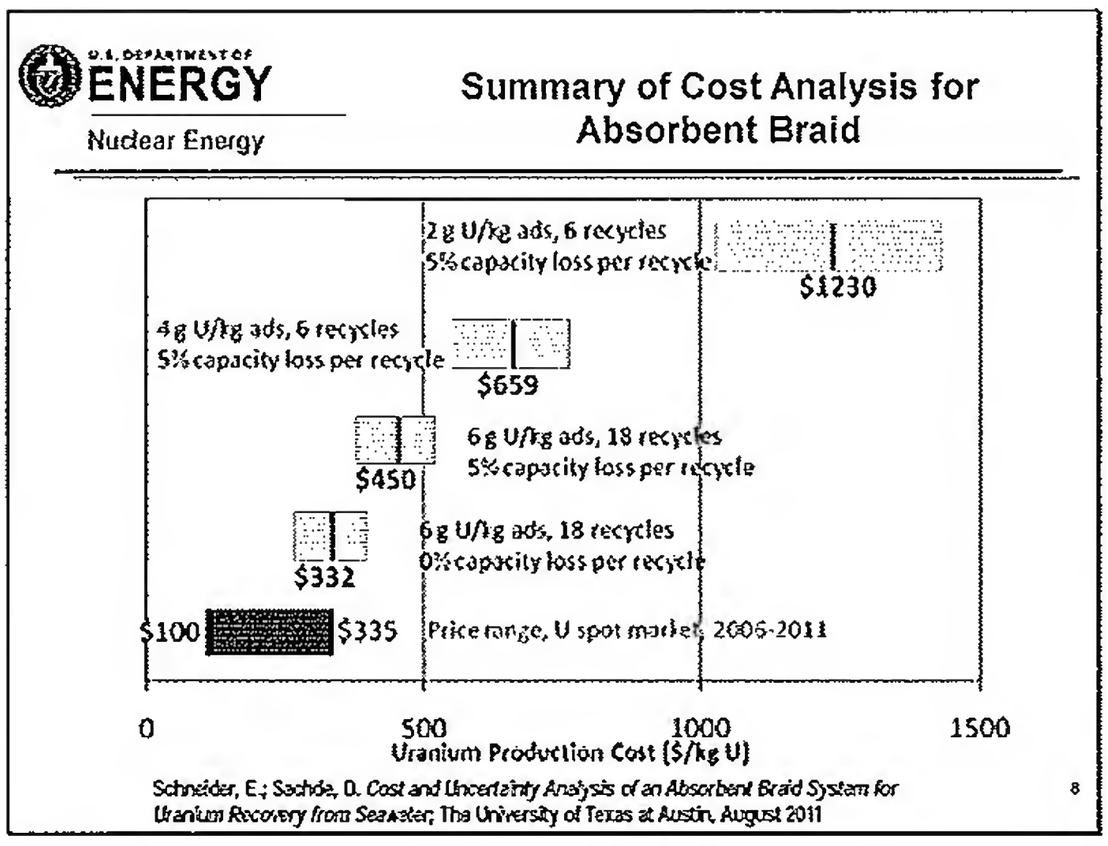

Slide 9

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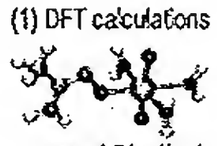
Preferred Uranyl Binding Motif with Amidoxime Ligand Identified

(1) DFT calculations



oxygen 4.5 kcal/mol

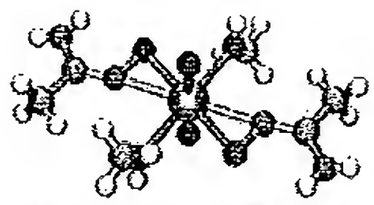
chelate 11.6 kcal/mol

η^2 0.0 kcal/mol

nitrogen

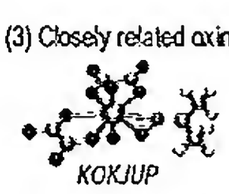
not stable

(2) X-ray structure

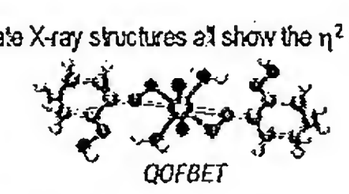


First structure of UO_2^{2+} –amidoximate confirms the η^2 binding motif

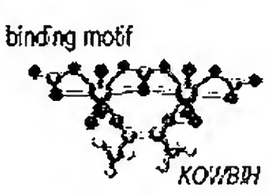
(3) Closely related oximate X-ray structures all show the η^2 binding motif



KOKJUP



QOFBET



KOVJBH

Vukovic, S.; Watson, L.A.; Kang, S.O.; Custelcean, R.; Hay, B.P., *"How Amidoximate Binds the Uranyl Cation", Inorg. Chem.* 2012, *51*, 3855-3859

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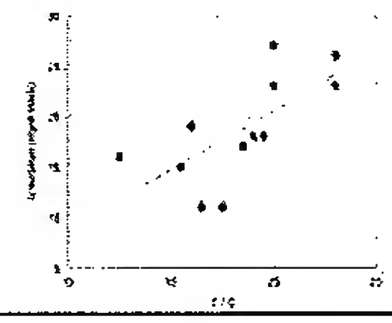
Thermodynamic Studies

$UO_2(CO_3)_3^{4-} + 2H_2A + H^+ = UO_2(HA)_2 + 3HCO_3^-$ $\Delta H = 35$ *kJ/M*

(a) $UO_2^{2-} + 2A^{2-} + 2H^+ = UO_2(HA)_2$	-154 kJ/M
(b) $UO_2^{2+} + 3CO_3^{2-} = UO_2(CO_3)_3^{4-}$	-39.2 kJ/M*
(c) $2H^+ + A^{2-} = H_2A$	-69.7 kJ/M
(d) $H^+ + CO_3^{2-} = HCO_3^-$	-14.7 kJ/M*

* Data for I = 0 (NEA database)

$UO_2(CO_3)_3^{4-} + 2H_2A = UO_2(HA)A^- + 3HCO_3^-$ $\Delta H = 16.7$ *kJ/M*



- Thermodynamic data suggest an "overall" endothermic reaction under seawater conditions, thus enhanced sorption at higher temperatures

Tian, G.; Teat, S. J.; Zhang, Z.; Rao, L. "Sequestering uranium from seawater: binding strength and modes of uranyl complexes with glutarimidedioxime", *Dalton Trans.* 2012, *41*, 11579-11586

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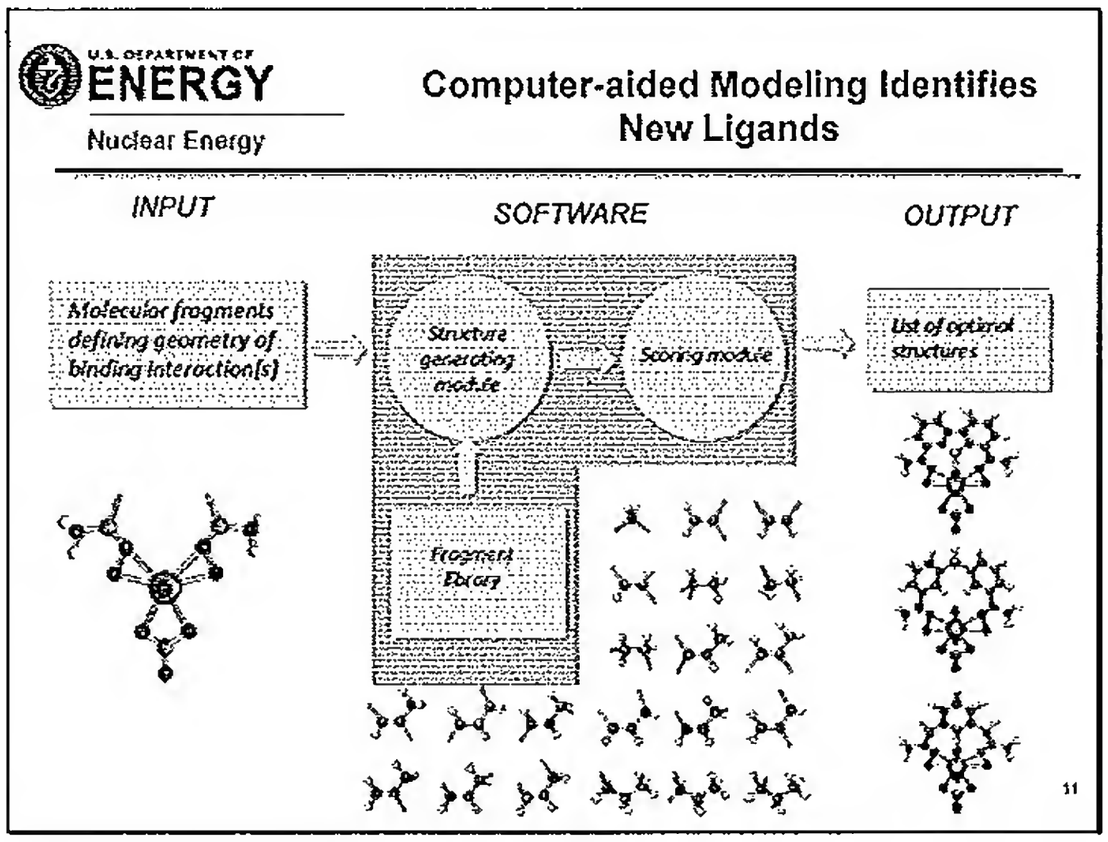
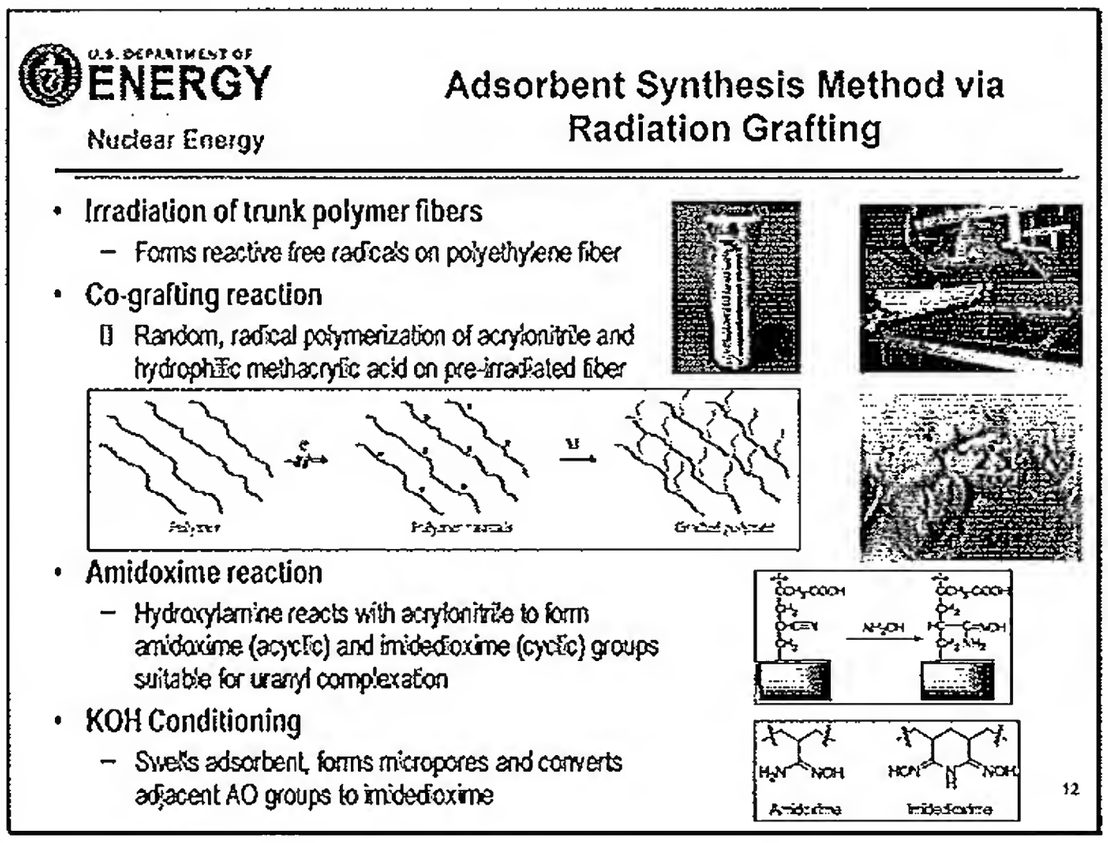
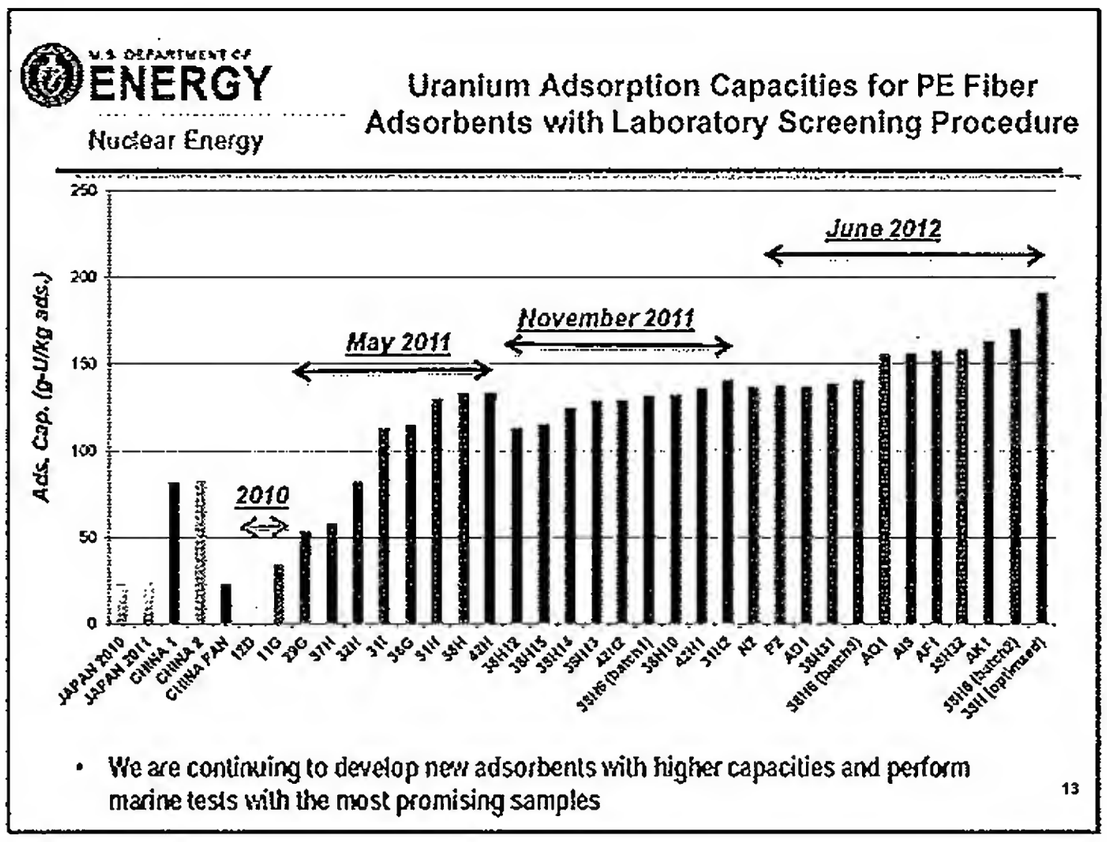


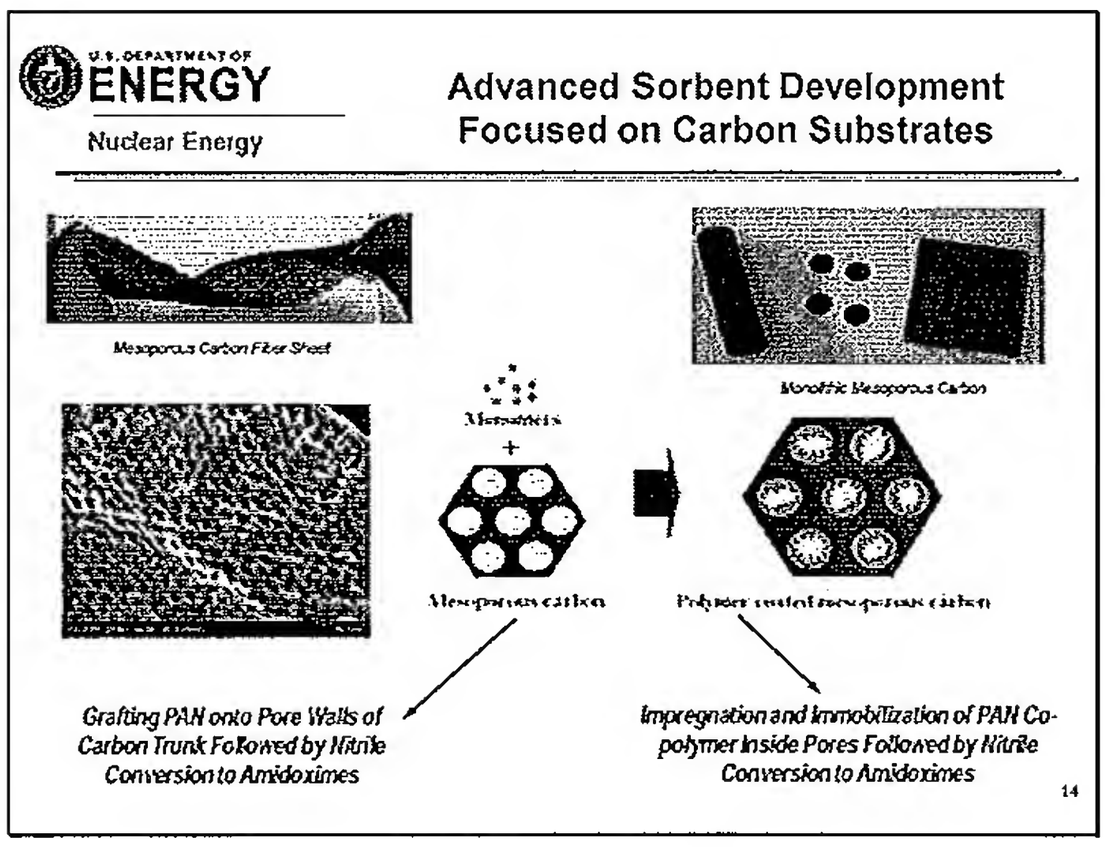
Slide 12



Slide 13



Slide 14



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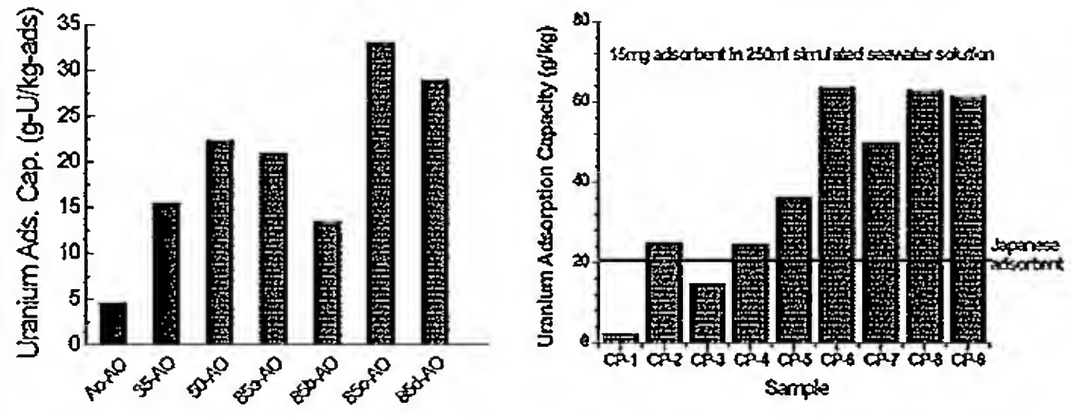
Nuclear Energy

Capacity Increased by Manipulating Pore Size Diameter



By manipulating the pore size, i.e. increasing pore diameters from 10 nm (in Ac-AO) up to 85 nm, and polymer immobilization method, the capacity increases dramatically (6 ppm U, simulated seawater)

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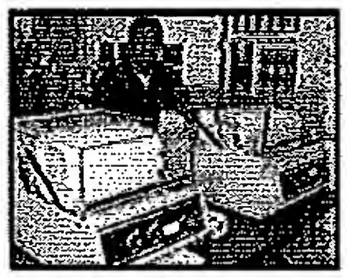
Nuclear Energy

Batch Equilibrium Testing with Real Seawater



Batch equilibrium experiments

Adsorbent	Capacity estimated from adsorbent (g-U/kg ads.)	Increase in capacity vs. Japan ads. (X) (After acid elution)	Distribution coefficient
Japanese Nonwoven	0.74	1	$2.5\ 10^5$
38H	3.94	5.3X	$1.7\ 10^6$
42H	3.55	4.8X	$1.4\ 10^6$

Results from ORNL adsorbents show higher uranium capacity than reference Japanese materials in actual seawater at 23 °C

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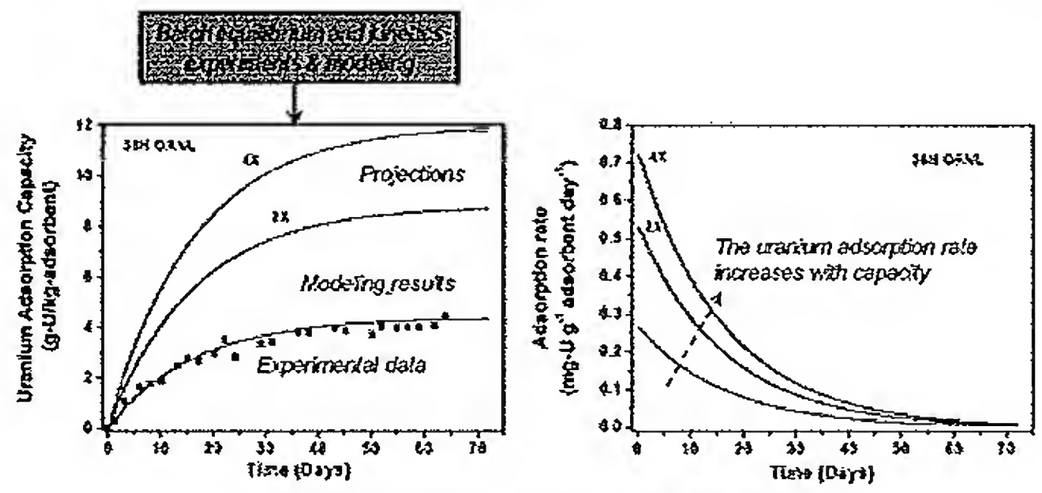
Modeling Results Show Adsorption Rate Increasing with Increasing Capacity



2X, 4X: increasing the capacity by 2 and 4 times

A higher adsorption capacity yields also faster kinetics of uranium uptake; therefore, the current focus is on increasing adsorbent capacity

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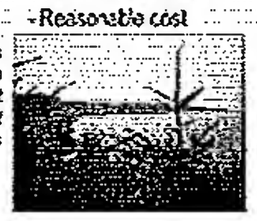
Selected Sites for Marine Testing

Location	Facility	Characteristics	Considerations
Sequim, WA	Pacific Northwest National Laboratory Marine Sciences Laboratory - DOE's only marine research laboratory		- Easy access to seawater - Excellent support - Analytical capabilities - Temperature control - Biofouling work
Miami, FL	Rosenstiel School of Marine and Atmospheric Science (RSMAS) – University of Miami		- Temperature - Remote area, away from urban discharge - Care taker available - Reasonable cost

RSMAS Broad Key Island facilities provide access to ocean currents with limited urban discharge

Sequim Bay provides pristine water from Pacific Ocean, significant tidal currents and test facilities



Recently added Woods Hole Oceanographic Institute on Cape Cod Peninsula as test site

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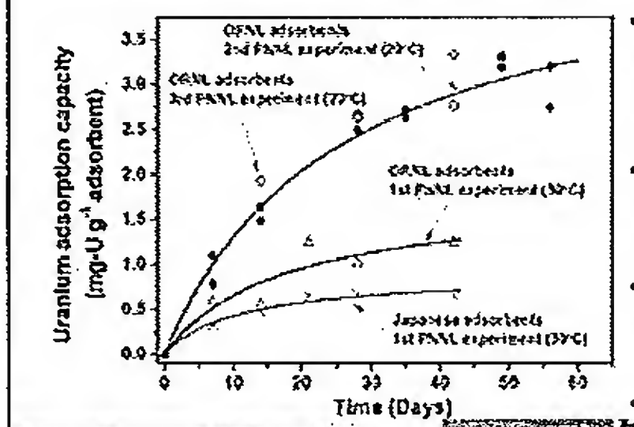
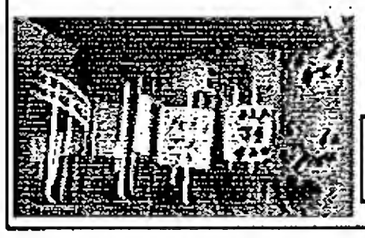
Marine Testing of Adsorbents at PNNL Flow-through Experiments



- At 30 C, the capacity of the ORNL adsorbent, after 6 weeks of contact with seawater, ranged between 1.2 and 2 mg U per g adsorbent
- At 30 C, the capacity for the Japanese adsorbent ranged between 0.6 and 0.7 mg U per g adsorbent
- At 20 C, the capacity of the ORNL adsorbent is approximately twice the capacity at 30 C
- This temperature effect is opposite to what is expected for an endothermic reaction, such as the reaction between the amidoxime group and uranyl



The temperature effect can be produced by competition of chemical species with uranyl ions for amidoxime groups

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Current Collaborative Efforts Between CAS and DOE

Slide 21

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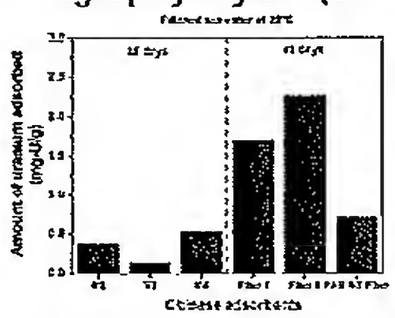
Nuclear Energy

Current Collaborative Efforts Between CAS and DOE

- Joint evaluation and marine tests of grafted ultrahigh molecular weight polyethylene (UHMWPE) adsorbents



- Exchange information (publications)
- Explore staff exchange for computational modeling of new ligands and adsorption behavior

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Nuclear Energy

Plans for Future Collaboration

- Investigate adsorption platforms for uranium from seawater and seawater testing experiments
- Investigate ligand design and computer modeling of uranium adsorption behavior
- New topics for future discussion
  - Molten salts (Point of Contact: Cecil Parks)

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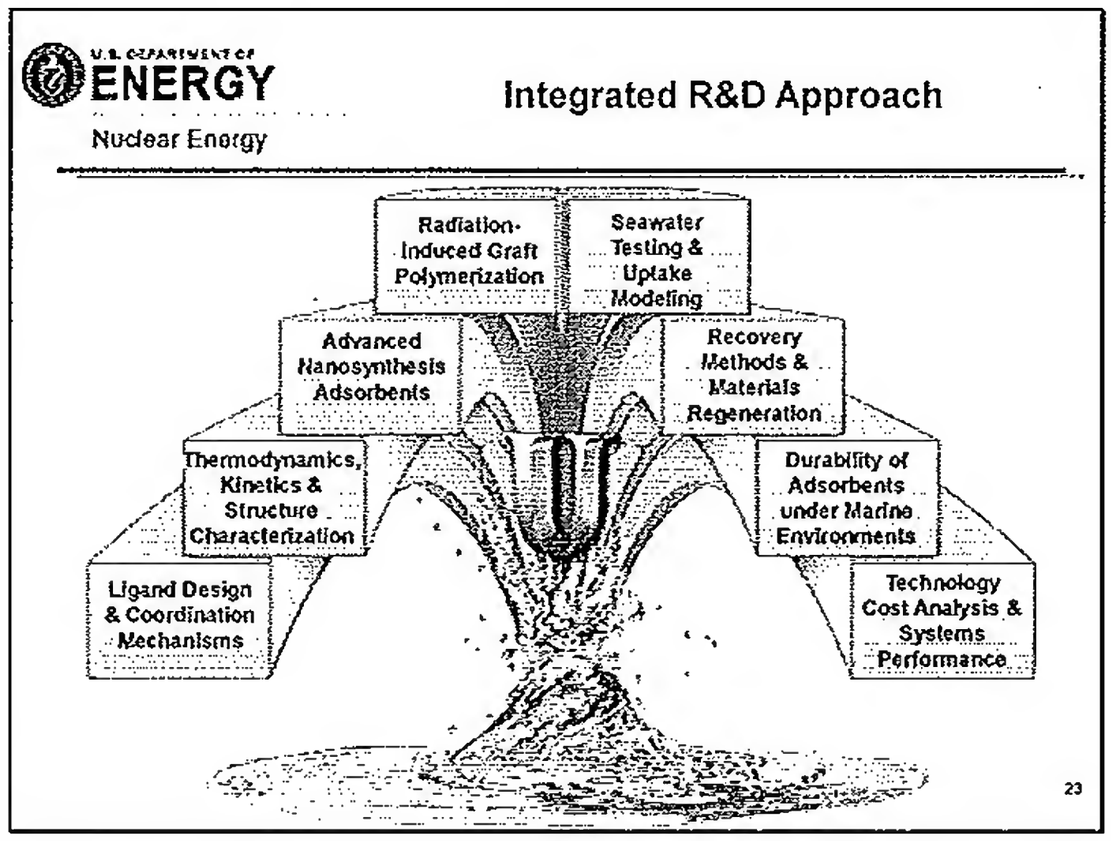
Slide 23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ENERGY
Nuclear Energy
Integrated R&D Approach
Radiation-Induced Graft Polymerization
Seawater Testing & Uptake Modeling
Advanced Nanosynthesis Adsorbents
Recovery Methods & Materials Regeneration
Thermodynamics, Kinetics & Structure Characterization
Durability of Adsorbents under Marine Environments
Ligand Design & Coordination Mechanisms
Technology Cost Analysis & Systems Performance
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Slide 1

October 22, 2012

U Extraction from Seawater Using Radiation Grafting Polyethylene Fiber

--- current status & next plan

Guozhong Wu

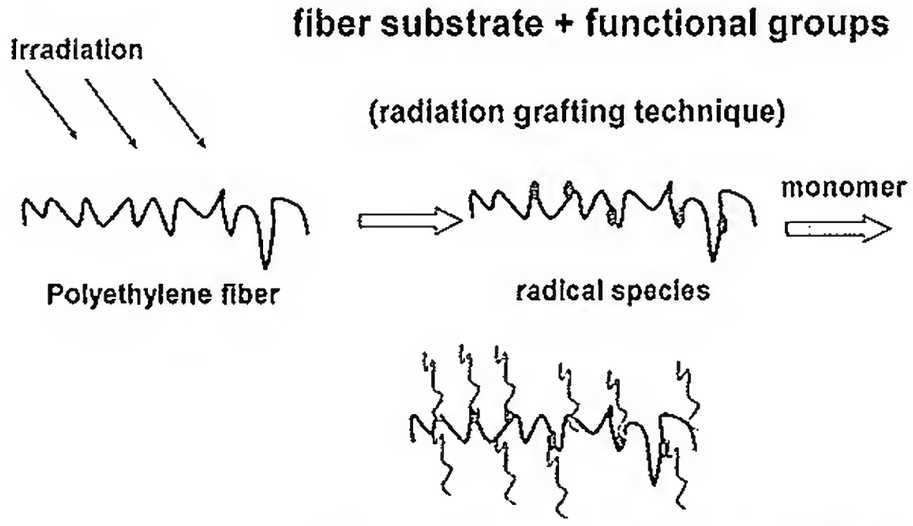
Shanghai Institute of Applied Physics, Chinese Academy of Sciences, China

Slide 2

Radiation modified fibrous material is optimal for U extraction in seawater

fiber substrate + functional groups

(radiation grafting technique)



(functionalized fiber with complexing group)

(amidoxime group is effective)

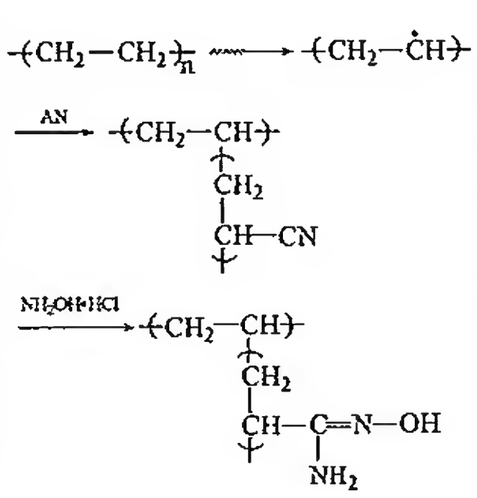
Slide 3

Current activity in SINAP

1) **Radiation grafting of acrylonitrile to non-woven fiber;**
2) **Radiation grafting of acrylonitrile to UHMWPE (ultra high moleculear weight) fiber;**
3) **Scale-up of radiation grafting processing**

Slide 4

Preparation of uranium adsorbent from PE nonwoven fabric by radiation induced emulsion grafting



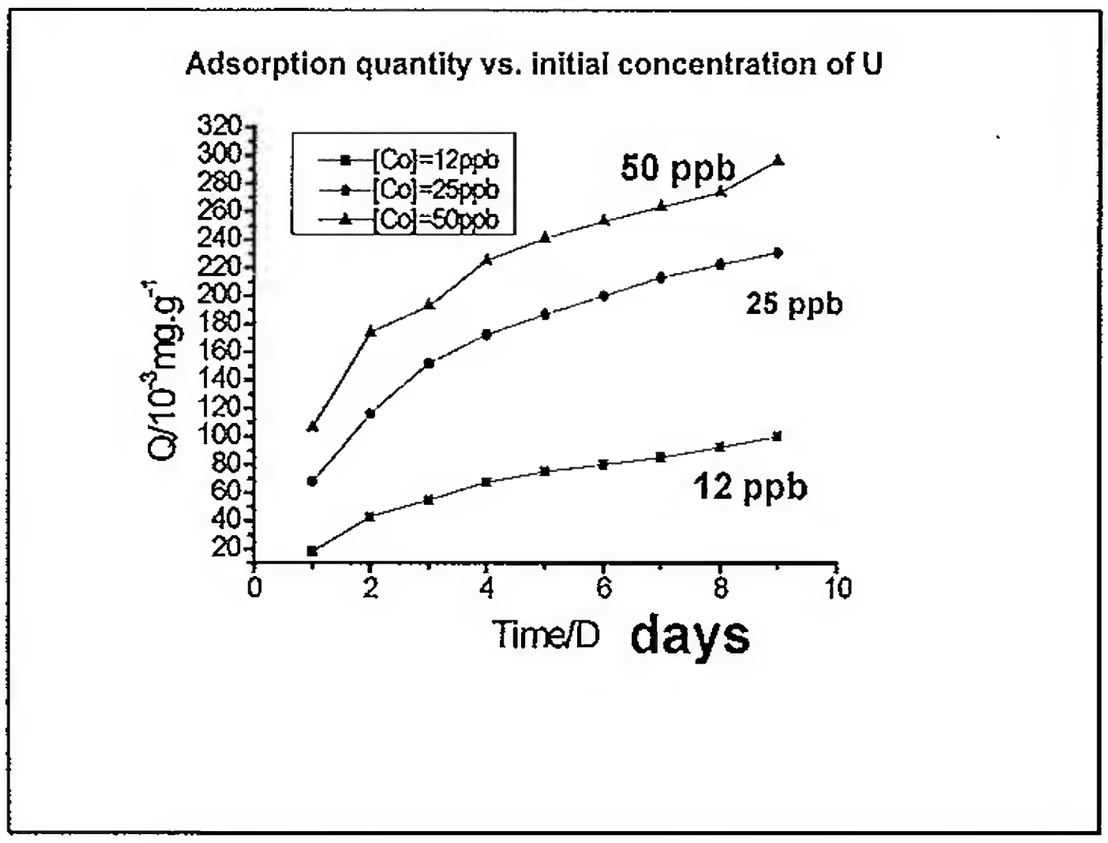
Advantages of emulsion graft polymerization :
Without organic solvents
High reaction rate
High monomer utilization ratio

Pre-Irradiation : 30 kGy, 10 % AN, emulsifier; 60 °C, 6 hrs

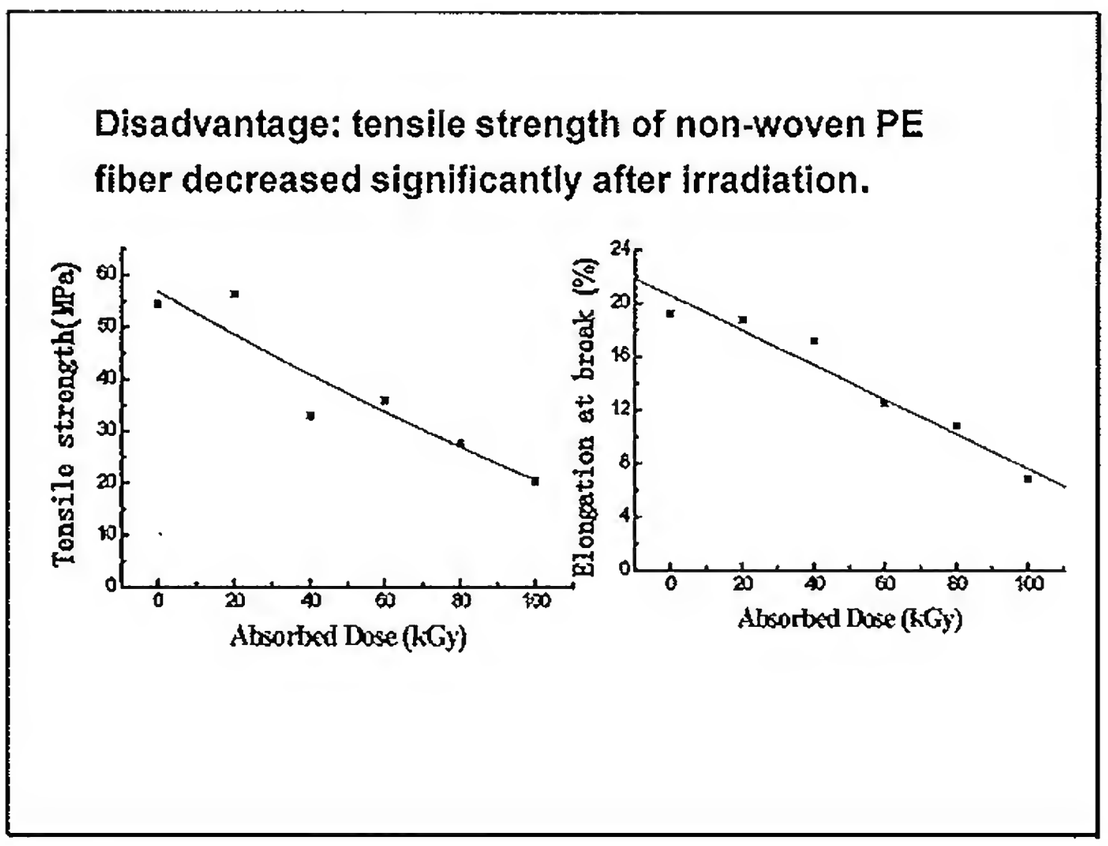
Uranium uptake is 1.4 mg-U/g-ad

Flowing water, U conc. 2.5-3.3ppb, T: 15-25°C, 70 days;
Elution: 1M $NaHCO_3$

Slide 5



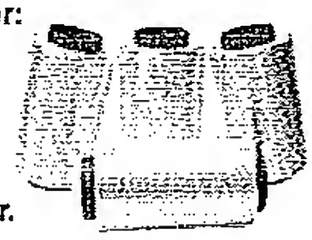
Slide 6



Slide 7

Our choice: UHMWPE fiber as the base material

Ultra-High Molecular Weight Polyethylene Fiber:



Advantage:

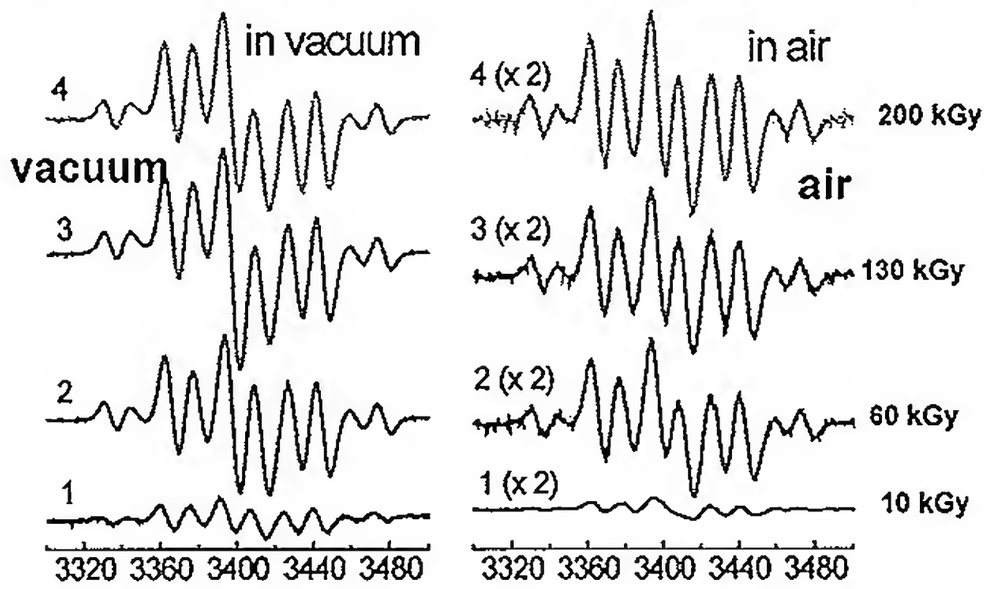
- **High strength and corrosion resistance**
- **Stable radical formation in UHMWPE fiber.**

Radiation Grafting of Acrylonitrile (AN) & Acrylic Acid to UHMWPE fiber

irradiation of Fiber in air ⟶ **Grafting of AN + AA**

Slide 8

Stable radical formation in UHMWPE fiber after irradiation

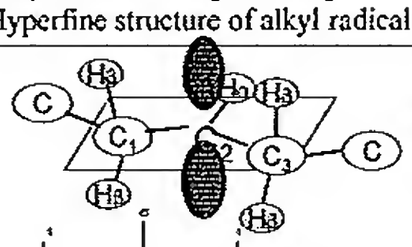


ESR spectra of the UHMWPE fiber irradiated in vacuum and in air at room temperature with a dose rate of 0.73 Gy/s. 1: 10 kGy, 2: 60 kGy, 3: 130 kGy, 4: 200 kGy. (×2) indicates the magnification of spectrum by a factor of two.

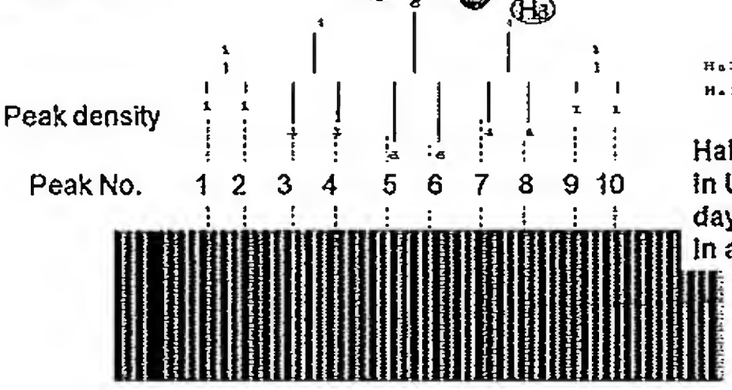
Slide 9

Alkyl radical: $-CH_2-\dot{C}H-CH_2-$
Hyperfine structure of alkyl radical

ESR spectrum is nearly identical to the theoretical calculation.



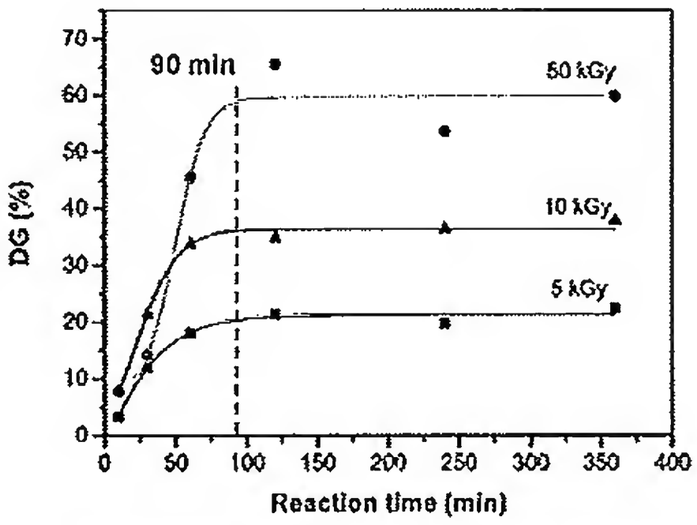
Extended PE:
Main chain C arranged in planner zigzag



Half-life of radical formed in UHMWPE fiber: 26 days in vacuum; 13 days in air.

$\Delta H_\beta = 4.6 \cos^2 30 = 3.5$ mT
4 H_β: equal hfs of 3.5 mT
H_α: 2.0-3.6mT (variable)

Slide 10

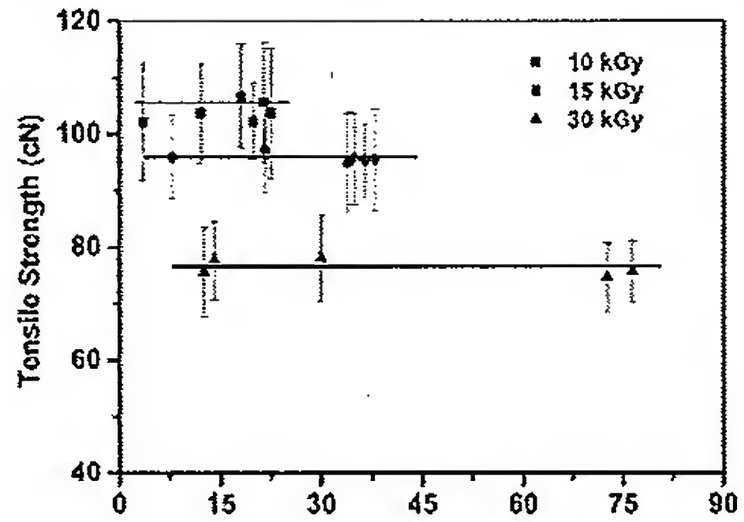


T=60°C,
DMF:AAc:AN=5:4:16 ,
$[Fe^{2+}]=4.5\times10^{-4}$ mol/L

Dependence of grafting degree on reaction time of UHMWPE fiber

Slide 11

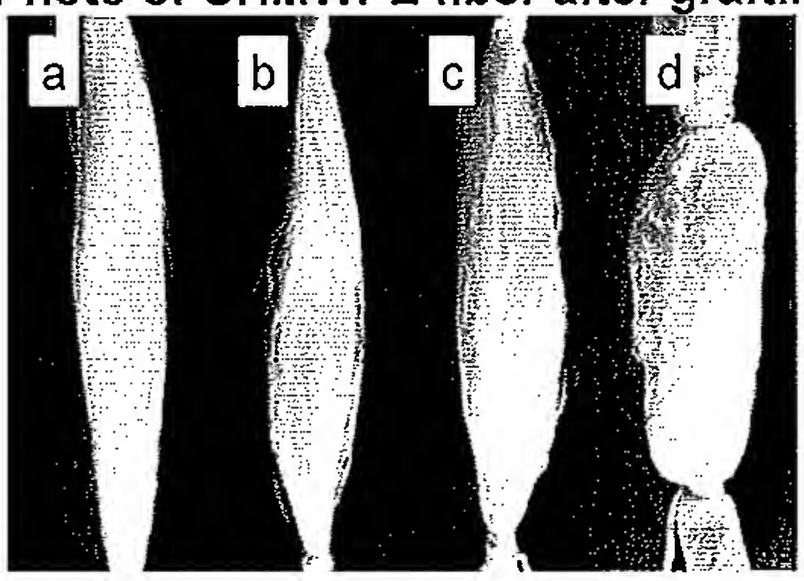
Dependence of tensile strength on DG of UHMWPE-g-(PAN-co-PAA) fiber



The grafting reaction has no effect on the tensile strength of UHMWPE fiber.

Slide 12

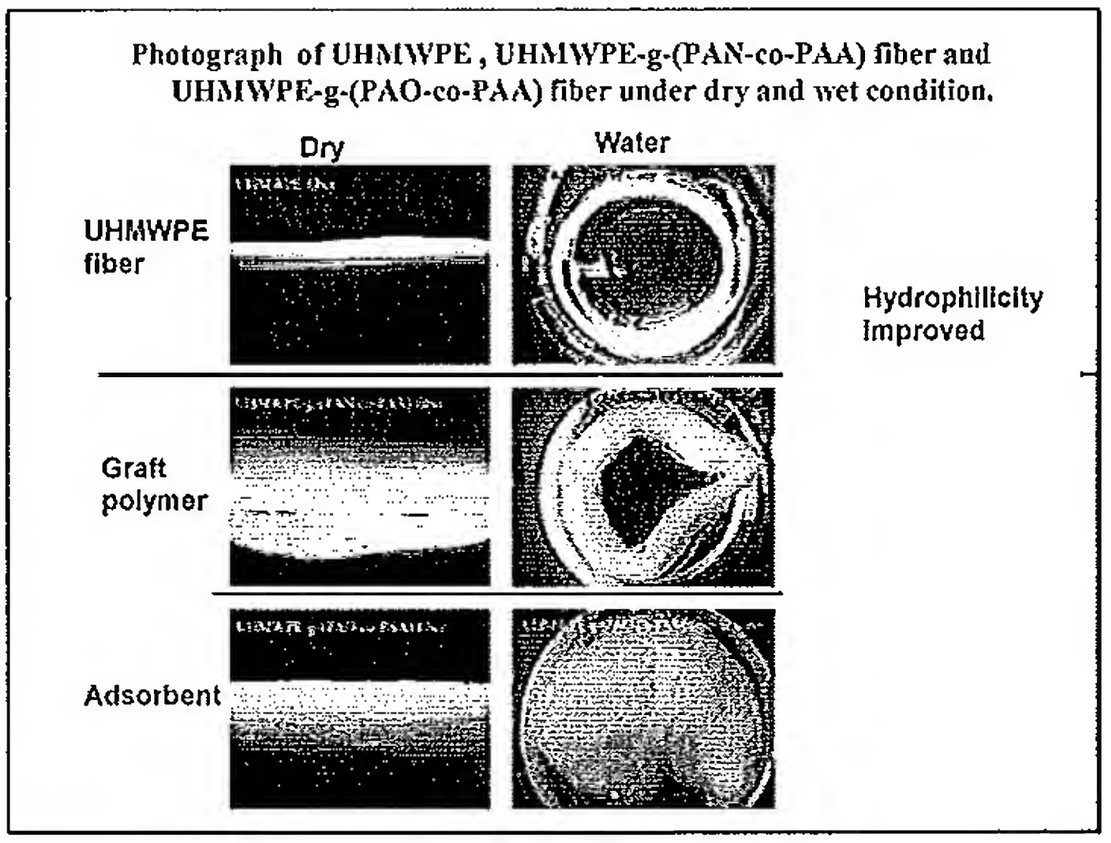
Photo of UHMWPE fiber after grafting



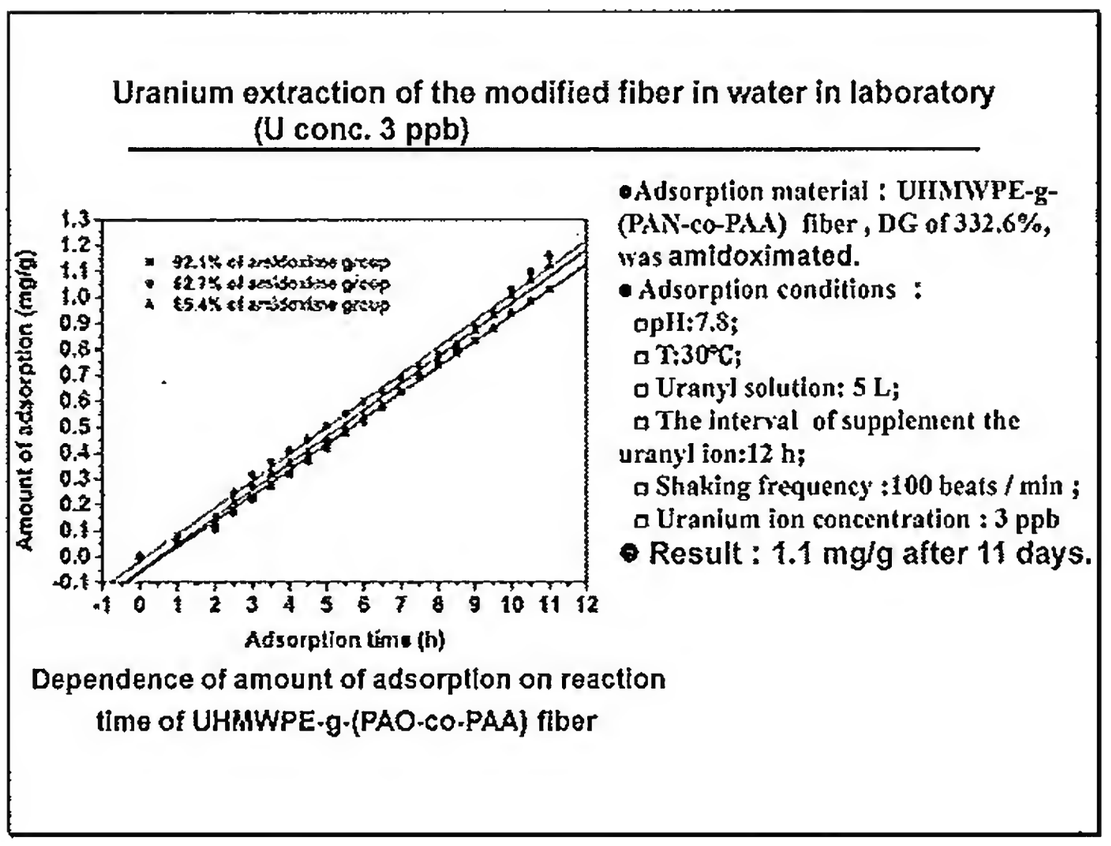
(a) UHMWPE fiber ; (b) DG 3.7% ; (c) DG 53.4% ; (d) DG 138%

Maximum: ~300%

Slide 13

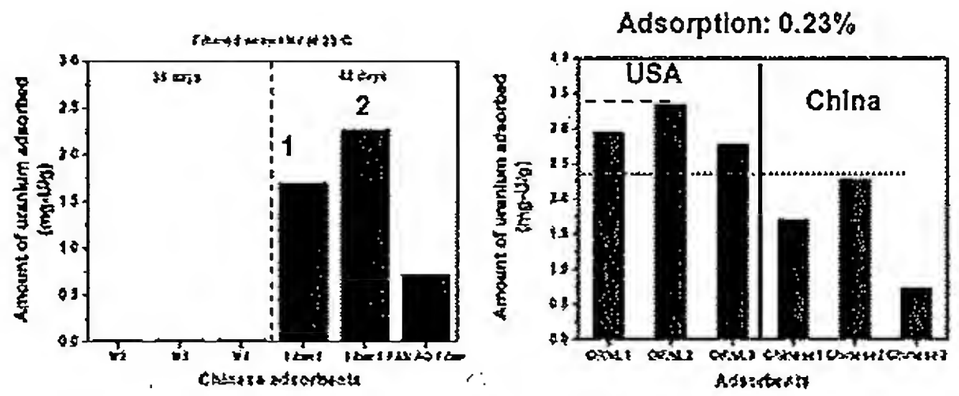


Slide 14



Slide 15

Marine test of the modified UHMWPE fiber in ORNL



Selectivity remains to be measured!

SINAP sample's adsorption quantity is lower than that of the US, but it should has much stronger tensile strength.

Slide 16

Future Plan in 2013-2014

1) Preparation of 1 kg grafted UHMWPE fiber in a batch;

2) Marine test of adsorption capacity and selectivity;

3) Scale-up of the adsorption material fabrication

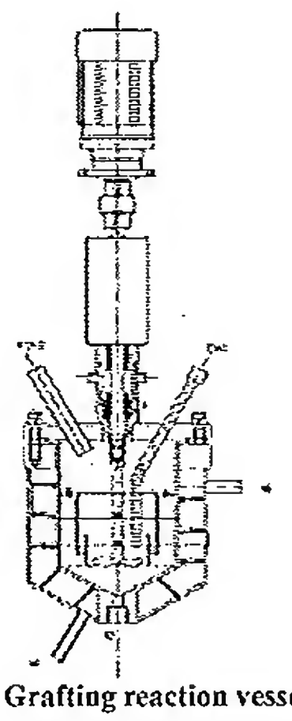
Slide 17

A reaction vessel for gamma irradiated UHMWPE fiber: design finished

Target: 1 kg/batch

The vessel put in glove box

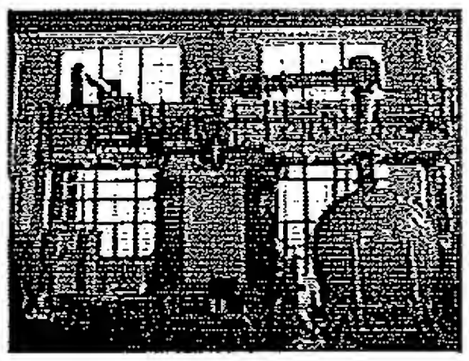
This is essential for the design of our future pilot plant.



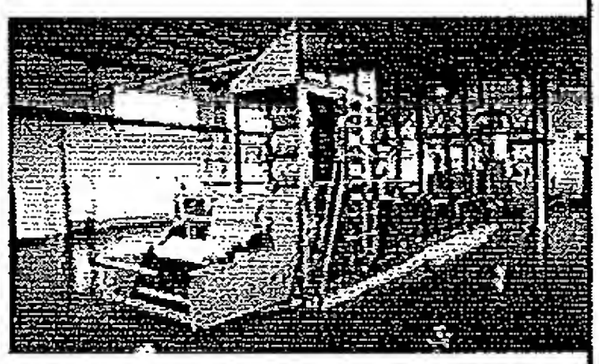
Grafting reaction vessel

Slide 18

Construction of a continuous pilot production line using low energy electron beam for adsorbent fabrication



(300-500 KeV accelerator)



(image) radiation grafting on non-wove fiber

Under Design, installation hopefully in summer of 2013

Slide 19

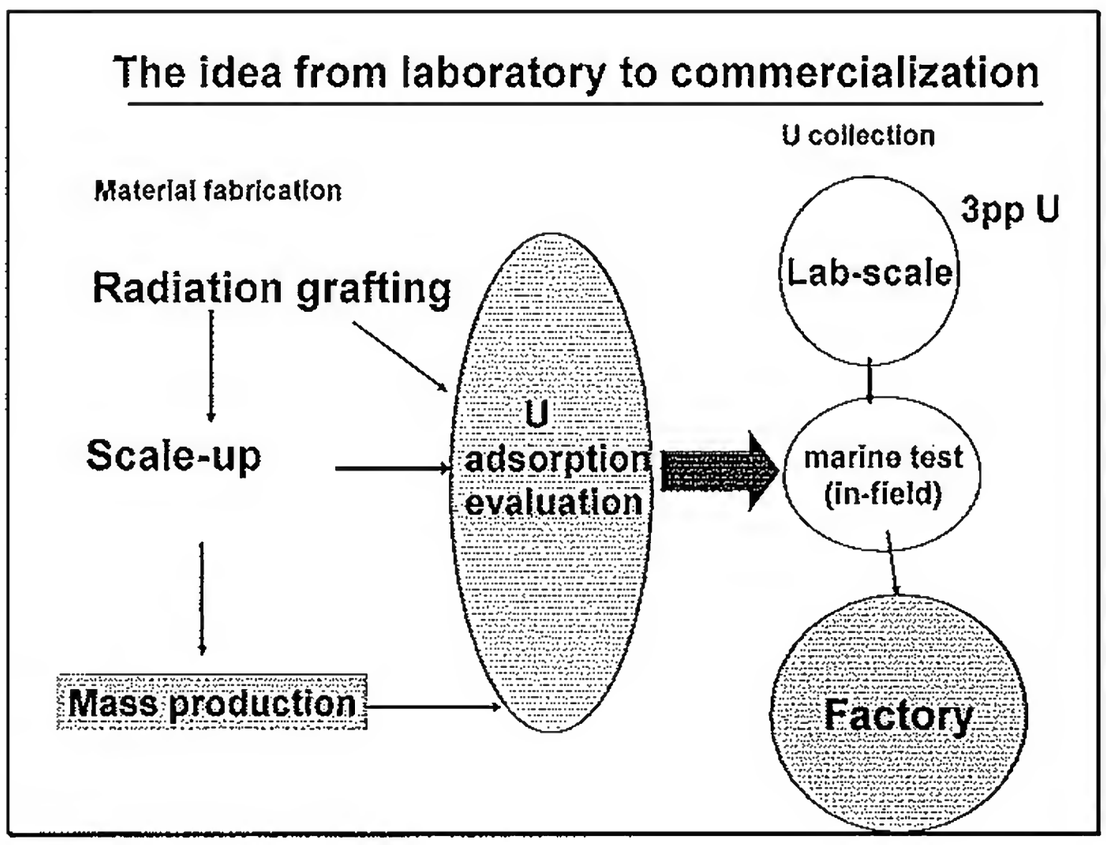
Adsorbent Evaluation

Uranium adsorption test in laboratory ;

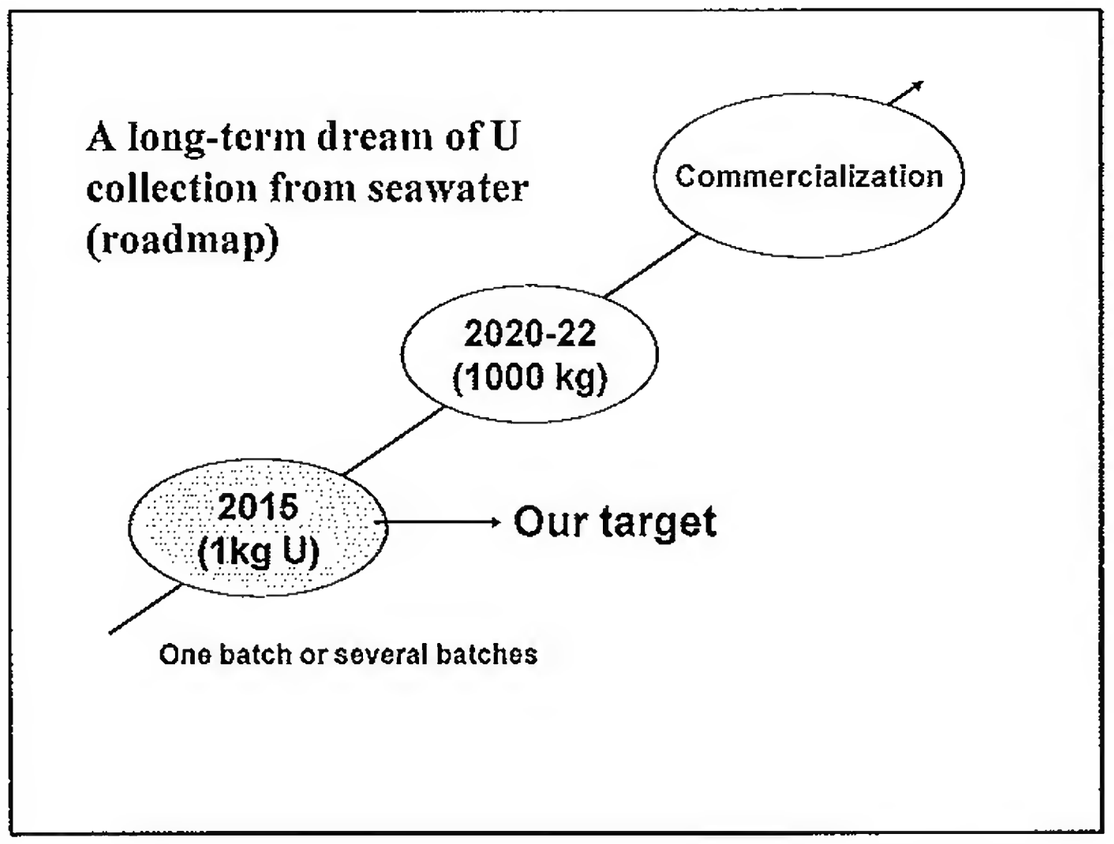
Two marine test locations to be constructed in 2013.

(one in south, the other in east; the location not decided yet)

Slide 20



Slide 21



Slide 22

Collaboration with the US is important for us

Some items

To pursue the collaboration and info exchange on grafting parameters for polyethylene fiber.

To continue collaboration on the marine testing and evaluation of sorbents, including the determination of kinetic data.

To explore potential collaborating on development of new sorbent materials with faster kinetics and higher capacity, including computer modeling.

Slide 23

Thanks for your attention!

Attachment H:

Hybrid energy Nuclear Energy Systems Working Group Meeting Presentation and Planned Future Activities

Slide 1

中国科学院
Chinese Academy of Sciences

Status and Progress in Collaboration of Nuclear Hybrid Energy System

Zhiyuan Zhu, CAS

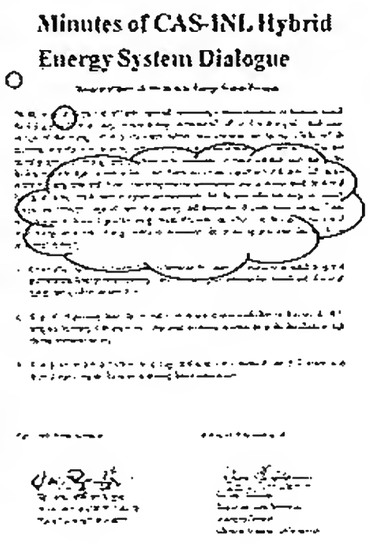
October 22, 2012 @ Shanghai

Slide 2

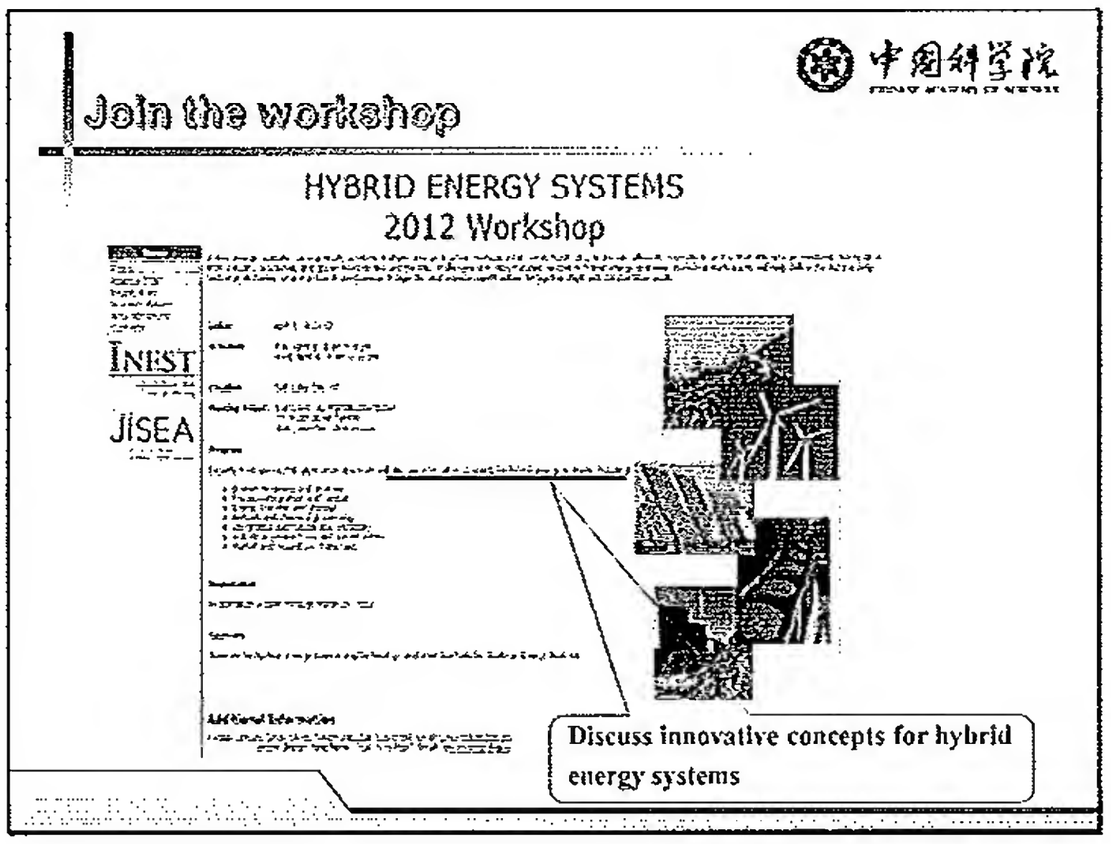
中国科学院

CAS-INL Common View about Hybrid Energy System

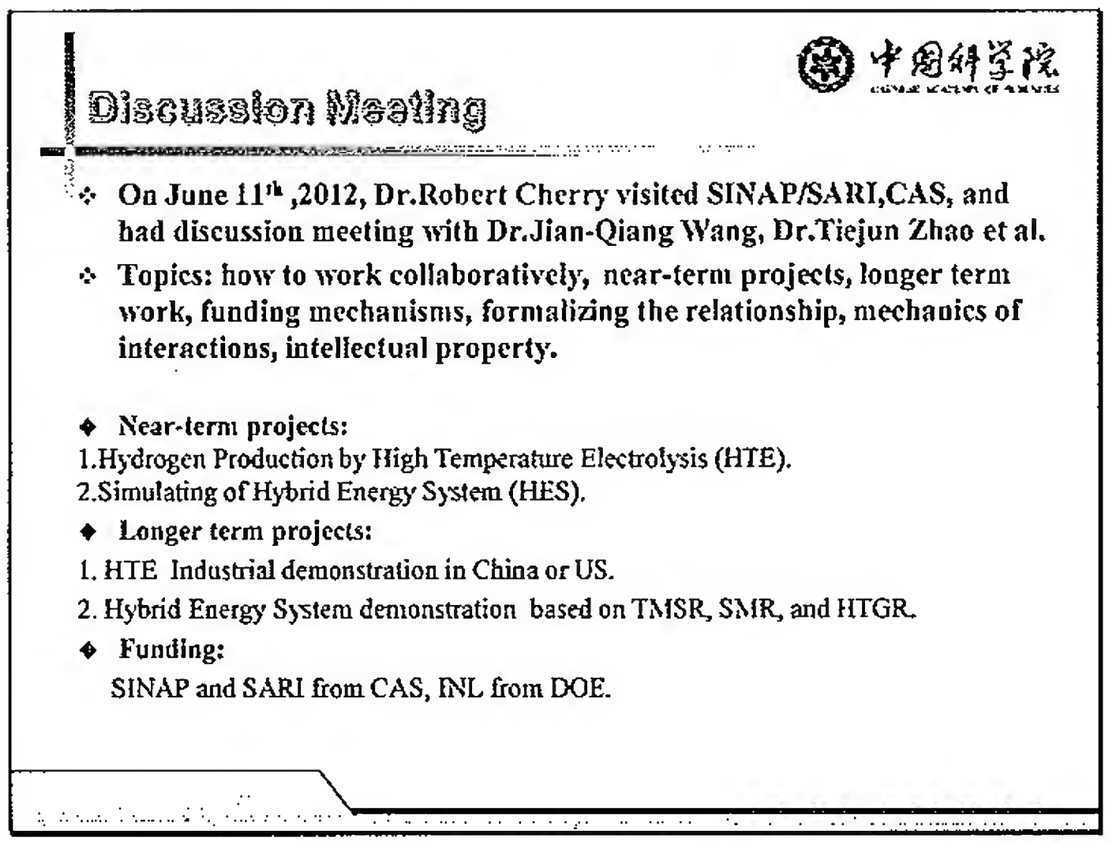
- **It was a common view that as the leading research organizations of the United States and China respectively, INL and CAS should establish a long-term and closer relationship on the development and implementation of Hybrid Energy Systems, which provide a potential opportunity for the more effective usage of nuclear energy and broader usage of renewable energy and expansion of clean fossil energy.**



Slide 3



Slide 4



Slide 5

video conferences

Subject: Invitation: Nuclear Hybrid Systems @ Wed Sep 5 6:30pm - 8:30pm (zhuzy@shb.ac.cn)
Date: 2012年9月6日星期四中国标准时间上午4时01分43秒
From: Richard D Boardman <richard.boardman@inl.gov>
To: zhuzy@shb.ac.cn <zhuzy@shb.ac.cn>, Glenda M Landon <glenda.landon@inl.gov>, Robert S Cherry <robert.cherry@inl.gov>, Hans D Gougar <hans.gougar@inl.gov>, Alexander Stanculescu <alexander.stanculescu@inl.gov>, Rick A Wood <rick.wood@inl.gov>, Shannon M Bragg-Sitton <shannon.bragg-sitton@inl.gov>

CAS/ INL held two video conferences on July 12th , 2012 and Sept. 6th,2012, respectively.

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Slide 6

Schedule of CAS / INL Collaboration

Task	*Schedule*	*Accomplishments / Milestone*
Review and Discuss Work Statement in a Tele Video Conference	July 12, 2012	Agree to workshop by email notification
Web-Based Project Kick-Off Meeting and Information Exchange	September 6, 2012	Agree on project technical assumptions and evaluation metrics; identify data exchange needs; review project execution schedule
HES Analysis	By November 30, 2012	Draft technical progress memos transmitted to CAS and INL, respectively
Conclusion Phase I technical and economical assessments	By March 30, 2013	Internal reports for organization review
Prepare a Journal Publication	By June 30, 2013	Submit manuscript to technical journal
Complete a Technology Readiness Assessment and R&D Gap Analysis	By August 31, 2013	Issue report to management on R&D needs and recommendations
Phase I Wrap-up Discussions and Memorandum	By September 30, 2013	Issue memorandum listing recommendations for Phase II collaboration

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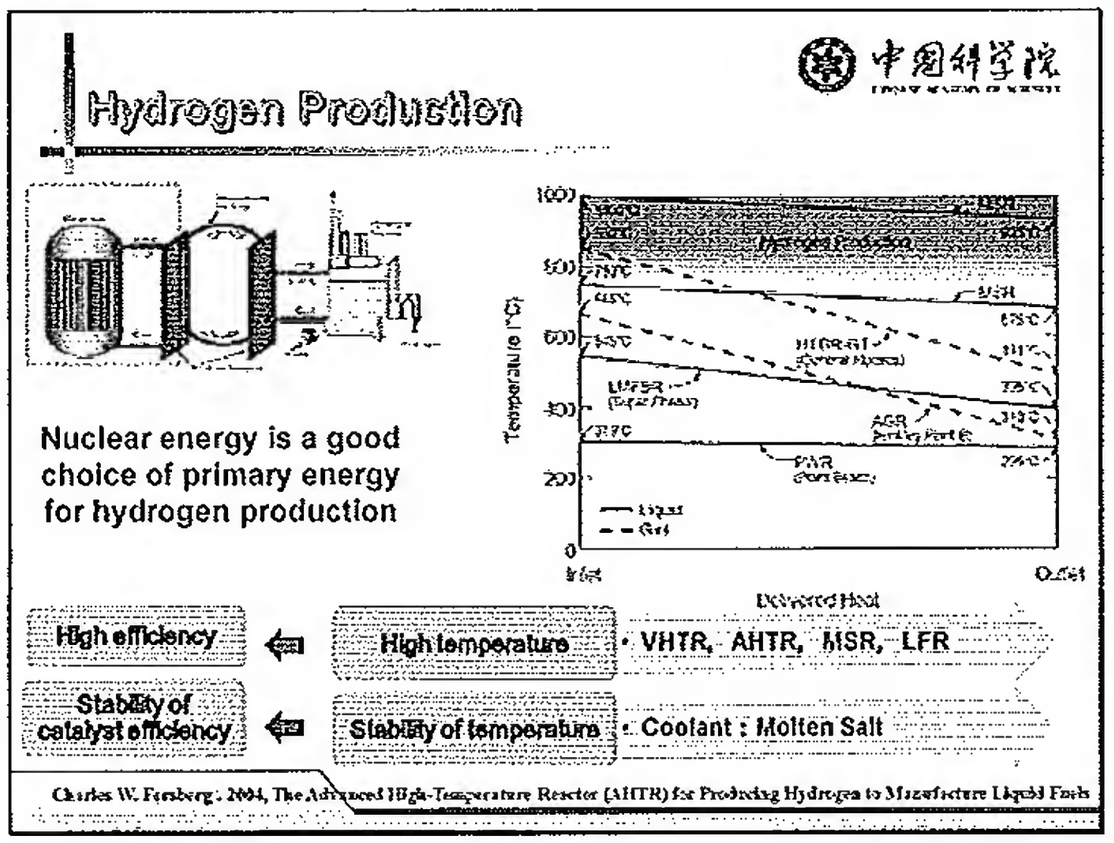

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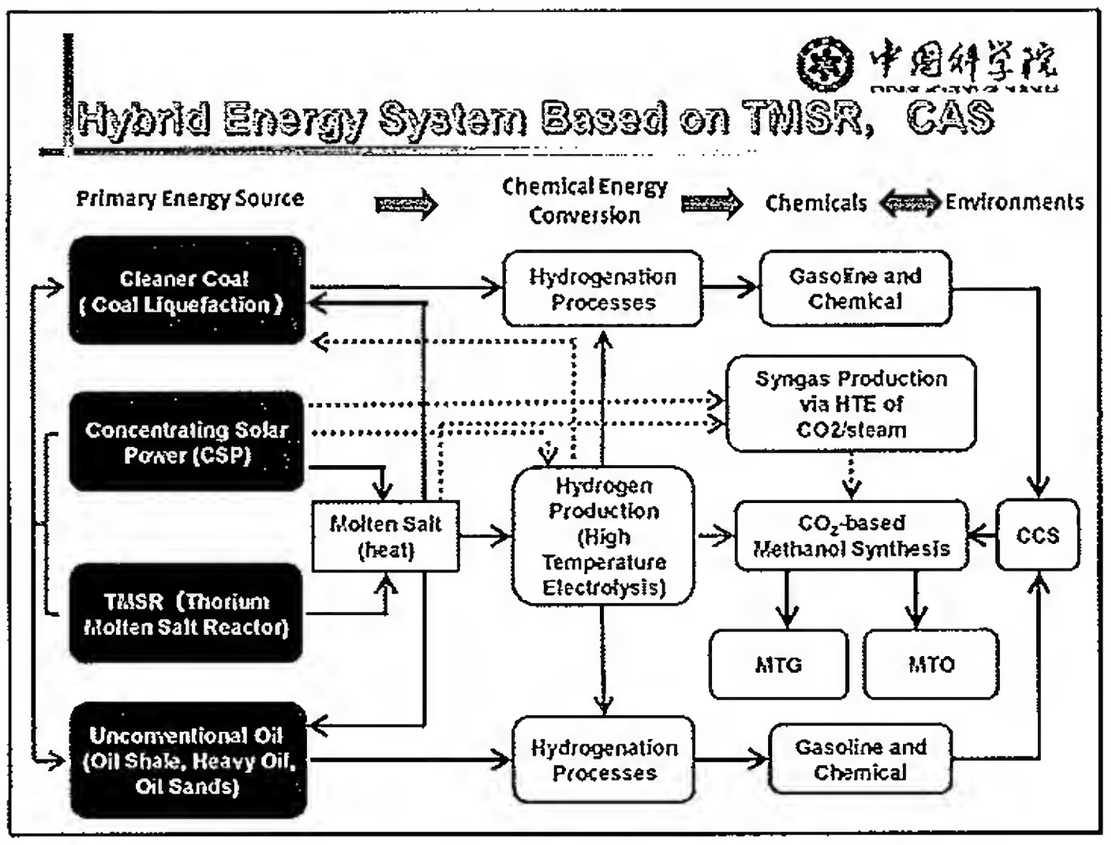

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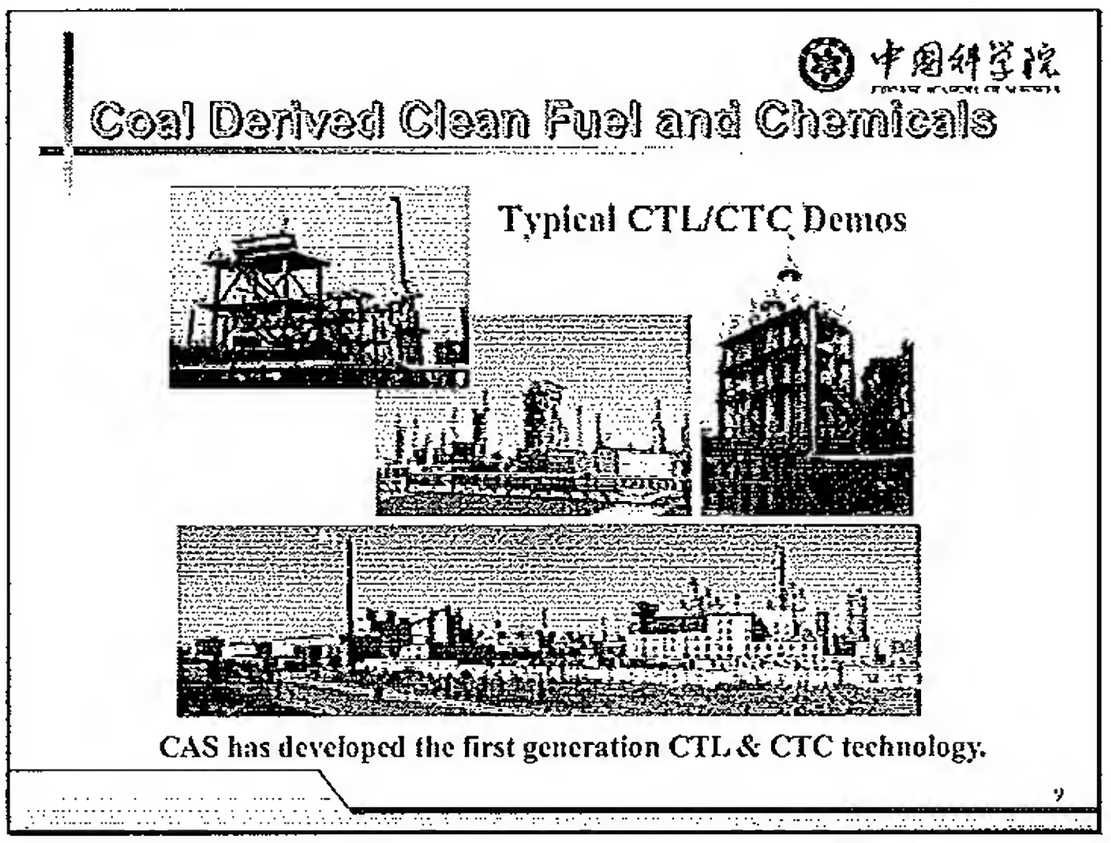

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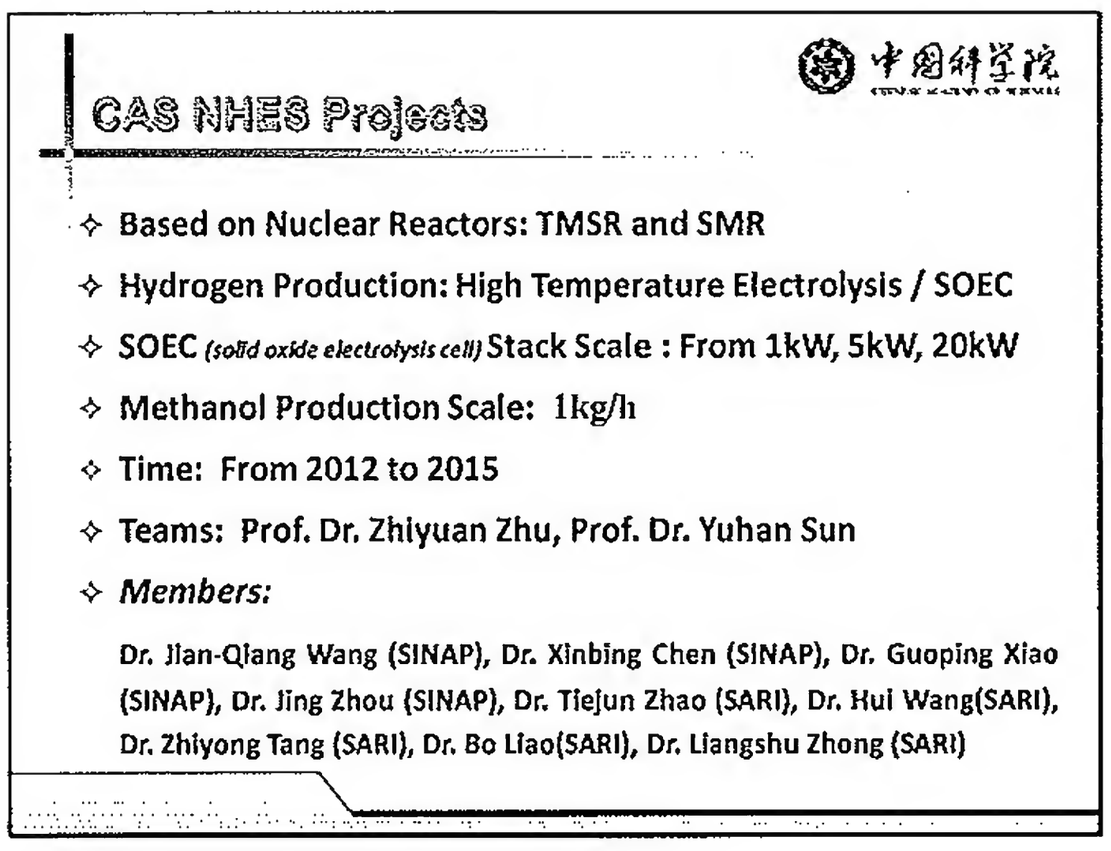

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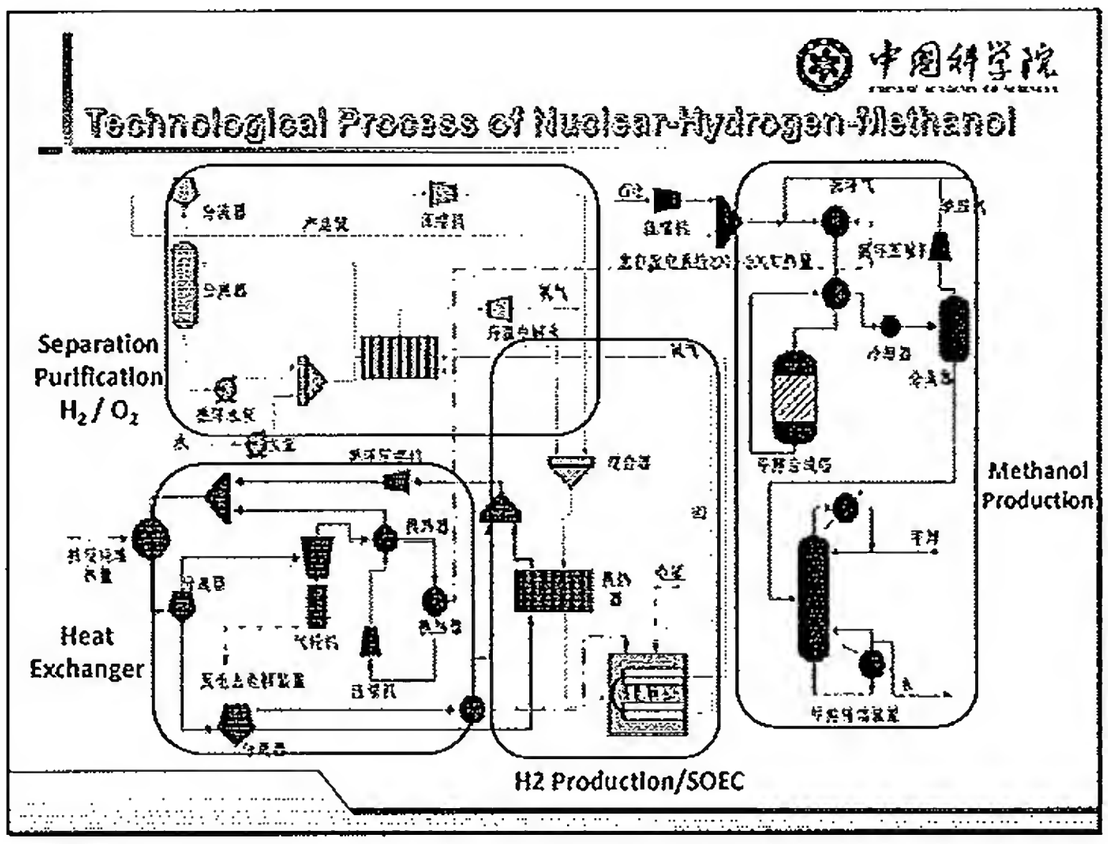

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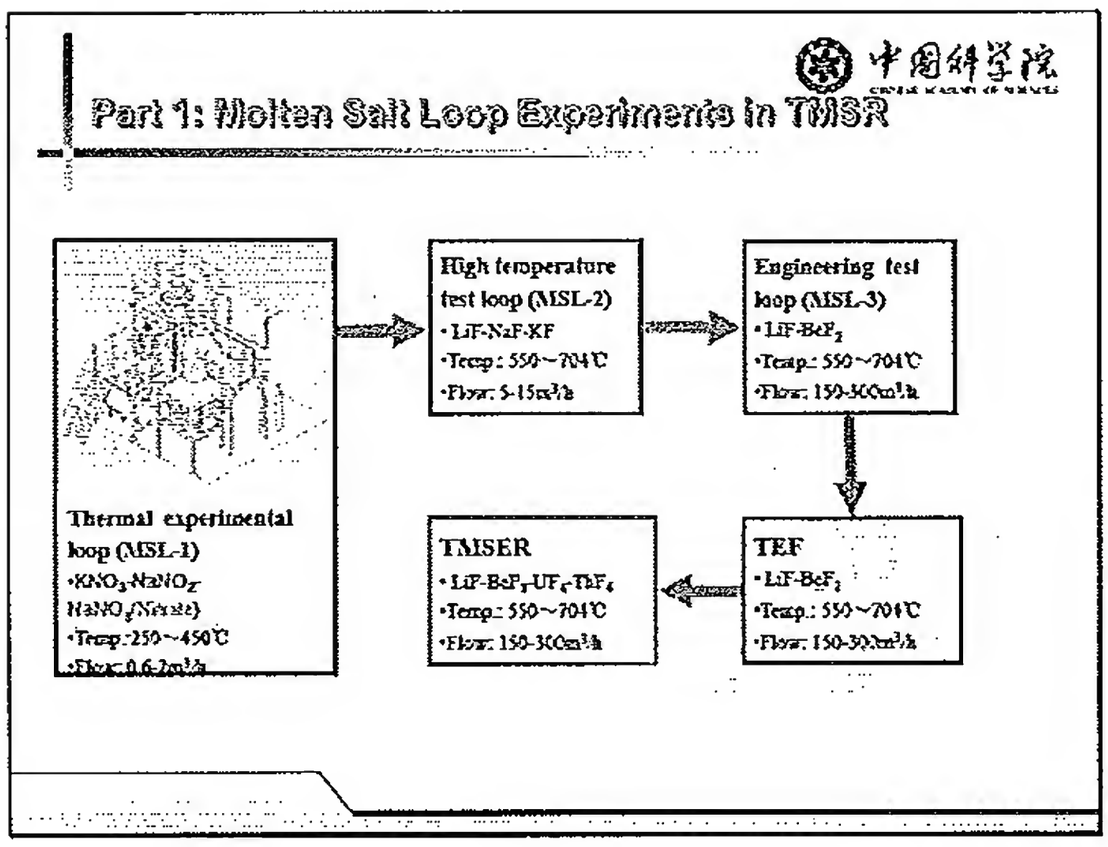

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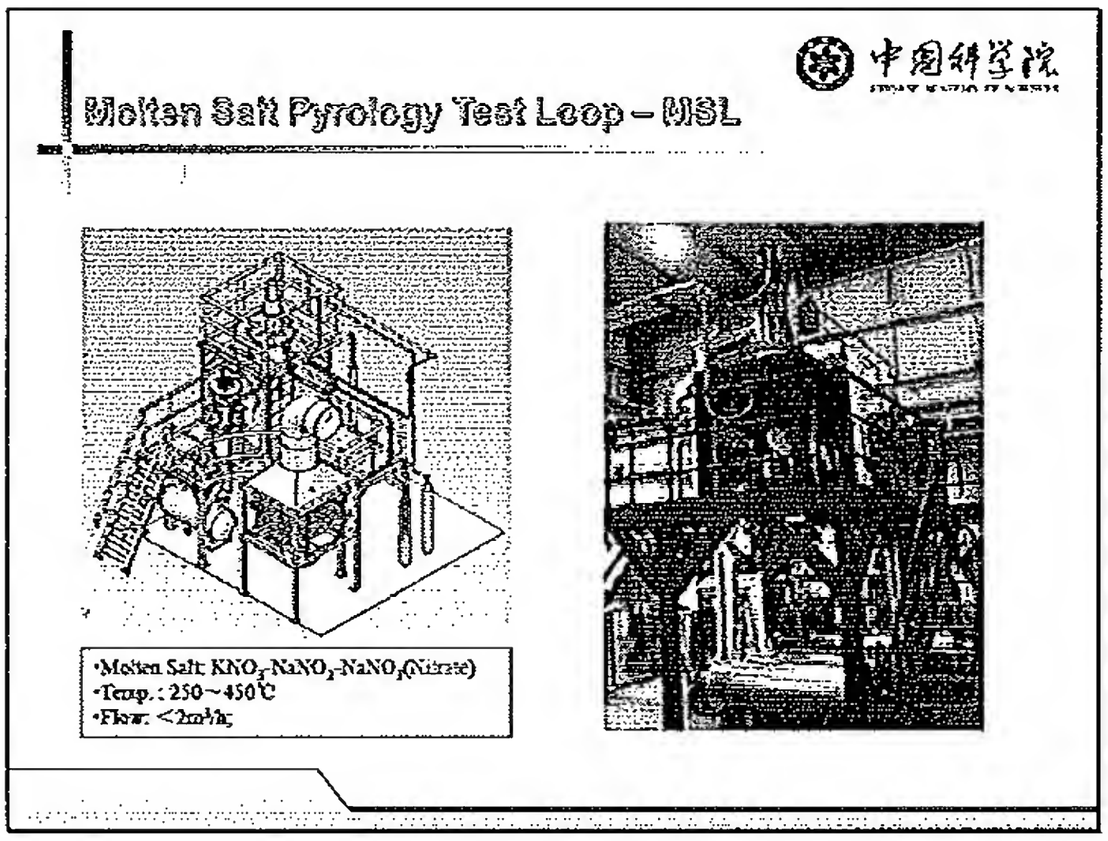

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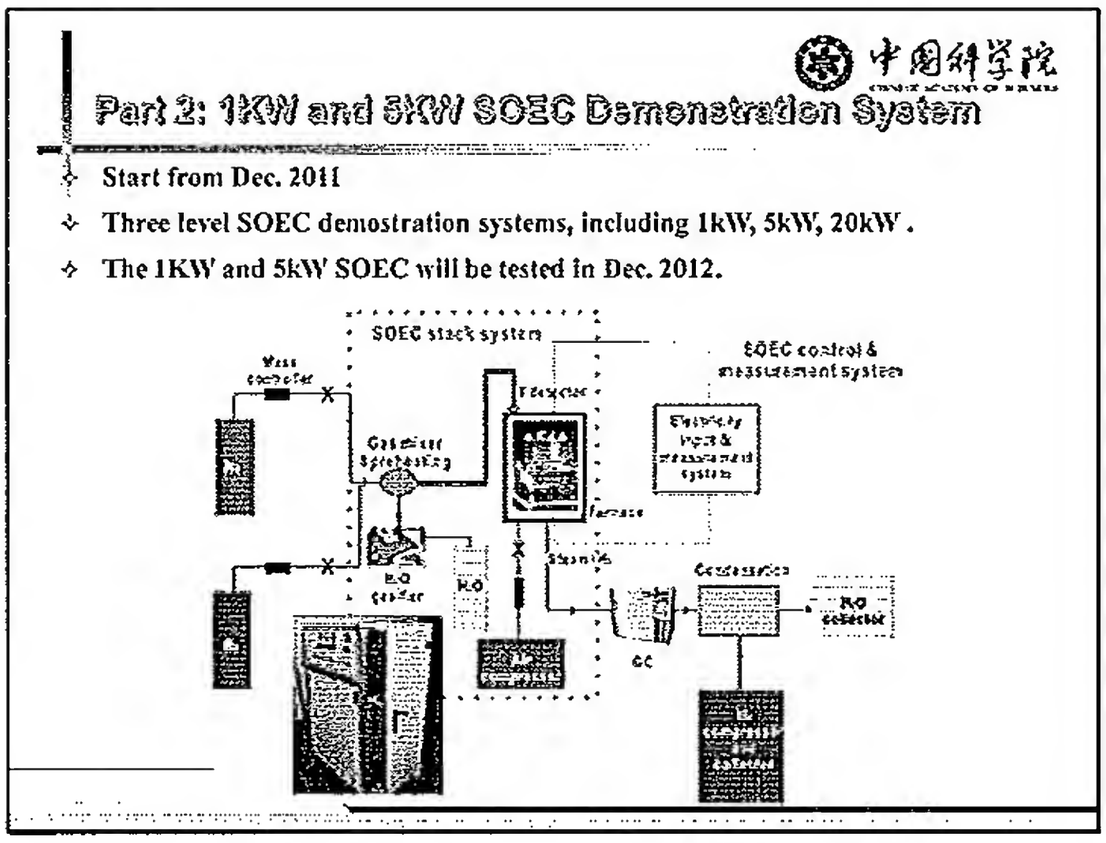

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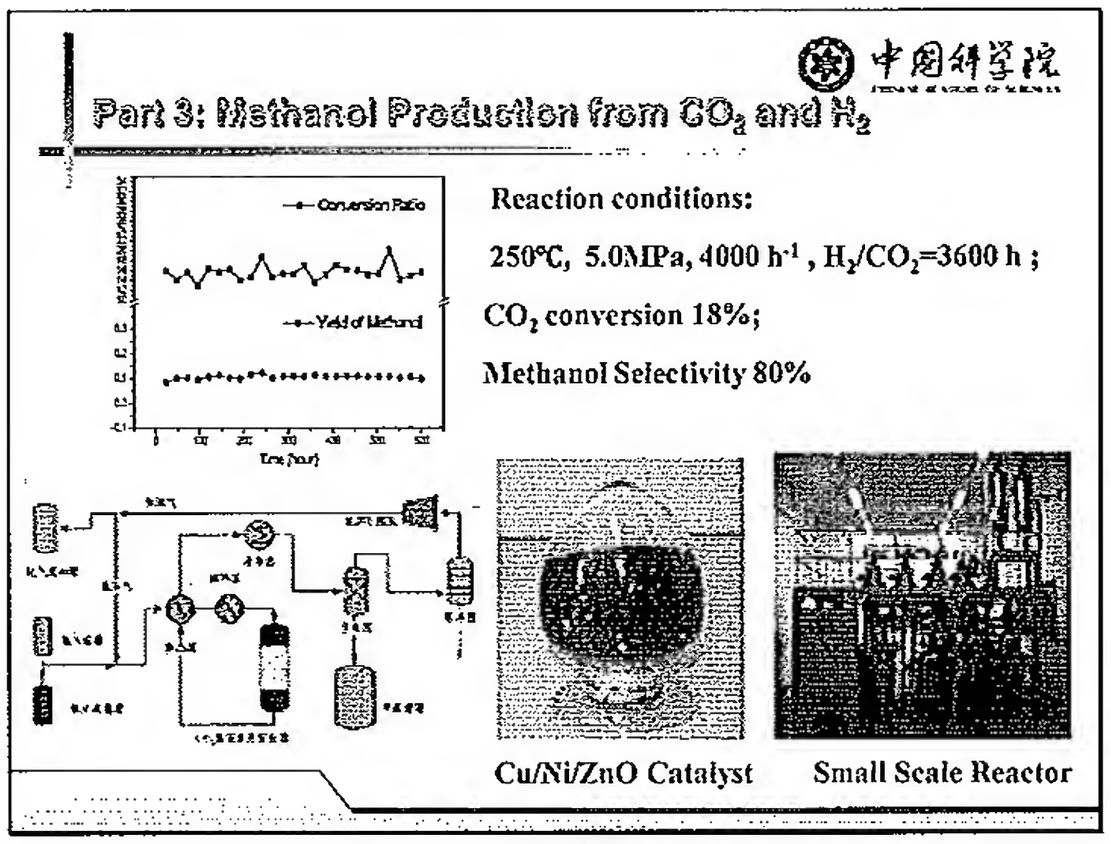

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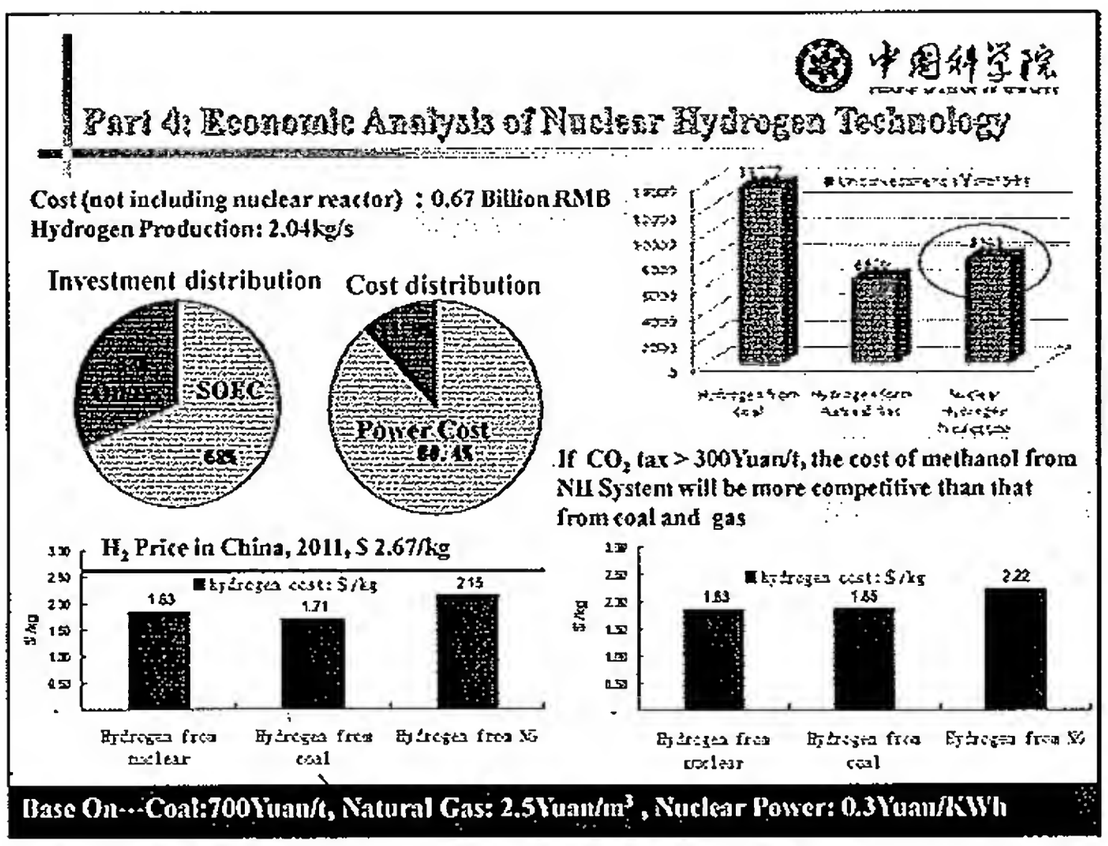

Slide 17

Conclusion and further plan

- CAS/ INL agree to develop economic routes to covert carbon source to normal fuels according to common work statement.
- Evaluate technique scheme of methanol production by HTGR, TMSR and SMR.
- Share model, research reports about hydrogen production by high temperature electrolysis and CO_2 hydrogenation to methanol.
- Explore the possibility of NHES demo in China.
- Hold a small symposium about nuclear hybrid energy system.
- Exchanging visit of staffs.

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Thanks for your attention.

MEMORANDUM OF UNDERSTANDING

BETWEEN

THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA

AND

THE CHINESE ACADEMY OF SCIENCES

ON COOPERATION IN NUCLEAR ENERGY SCIENCES AND TECHNOLOGIES

The Department of Energy (DOE) of the United States of America, and the Chinese Academy of Sciences (CAS) of the People's Republic of China, hereinafter referred to as the "Participants":

NOTING their desire to enhance communication and cooperation on nuclear energy-related matters of common interest and to foster collaboration among scientists, laboratories, research institutes and universities of the Participants' countries and to facilitate and promote cooperation in research and development in a broad range of nuclear energy sciences and technologies; and

NOTING the Agreement for Cooperation between the Government of the United States of America and the Government of the People's Republic of China Concerning Peaceful Uses of Nuclear Energy, signed at Washington on July 23, 1985,

Have reached the following understanding:

Section 1
Objective

1. The objective of this Memorandum of Understanding (Memorandum) is to promote and facilitate cooperation on the scientific and technical aspects of nuclear energy technologies.

2. By their joint determination, the Participants may invite other entities to participate in the cooperative activities carried out in the framework of this Memorandum: governmental agencies, universities, science and research centers, institutes and institutions, private sector firms, and other entities of the Participants' respective governments. The costs of such participation are the responsibility of the entities that incur them.

3. The Participants' cooperation under this Memorandum is intended for peaceful purposes only.

Section 2
Forms of Cooperation

1. Forms of cooperation under this Memorandum may include: exchange of publicly available technical information, data and experience; exchange of technical and managerial personnel for visits and short-term assignments; exchange of equipment, materials and instrumentation; joint conferences, seminars or workshops; and such other forms of cooperation as the Participants may jointly decide in writing.

2. The terms of visits and assignments, and the exchange of equipment, materials, and instrumentation should be the subjects of appropriate written agreements between the sending and receiving entities.

Section 3
Areas of Cooperation

1. Priority areas of cooperation may include the following:

<u>Nuclear Energy for Non-electric Applications</u>
Nuclear power could be used to displace greenhouse gas emitting fuels in the industrial sector. Petroleum refining, for example, requires temperatures in the range of 250-500°C while steam reforming of natural gas requires process heat in the 500-900°C range. Achieving higher output temperatures requires switching to a new coolant technology such as molten salt. With advanced coolants, it is possible to achieve outlet temperatures ranging from 500°C to over 900°C.

Potential subjects of collaborative activities may include materials and chemistry of fluoride salt coolant systems.

Nuclear Fuel Resources

Nuclear energy can help alleviate the concern over greenhouse gases and global warming, energy supply security, and high and volatile fossil fuel prices. For nuclear energy to remain a viable and sustainable energy source, there must be assurance that economical sources of nuclear fuels are available. The focus of this cooperation is direct extraction of dissolved uranium from seawater. Although uranium is present in very low concentrations in seawater, 3.3 parts per billion, the oceans contain over 4500 million tonnes of uranium, which would provide essentially unlimited supply of nuclear fuel. Potential subjects of collaborative activities may include: (a) molecular-level understanding of the coordination modes, sorption mechanisms, and kinetics of uranium extraction; (b) new functional ligands; and (c) advanced sorbent materials.

2. The areas of cooperation may be expanded and revised by the written consent of the Participants.

3. The Participants intend to conduct research and development on mutually determined subjects under appropriate written agreements therefor. Such agreements should include, among other matters, provisions for the protection and allocation of intellectual property.

Section 4
Management

1. Execution of this Memorandum is to be guided by an Executive Committee (EC) consisting of one co-chair from each Participant: DOE Assistant Secretary for Nuclear Energy and Vice President of CAS.

2. The EC co-chairs should designate one technical coordinator from each Participant to organize technical activities under this Memorandum. The technical coordinators should jointly plan, identify, and coordinate cooperative activities. Specific working groups may be established to collaborate on mutually determined topics.

3. Working groups and/or EC meetings should take place on an annual basis or as otherwise mutually decided, alternately in the United States and in the People's Republic of China.

4. The host Participant should choose the meeting site and bear the costs for the arrangements associated with the meeting. Representatives from each Participant attending the meetings are to be responsible for their own travel and lodging expenses.

5. The technical coordinators should jointly prepare written reports of the meetings. Each Participant may disseminate the written meeting report without prior notification to the other Participant, after the record has been approved by EC. The report should document the progress of activities and the next year's plans for continuation of cooperation.

6. The technical coordinators may invite representatives of other organizations within their countries to attend joint working groups and/or EC meetings.

Section 5
General Considerations

1. This Memorandum does not constitute a legally binding agreement.

2. Each Participant should implement this Memorandum in accordance with the laws, regulations and other requirements of its respective country and international agreements to which its government is party.

3. Any questions relating to this Memorandum arising during its term should be resolved by consultations between the Participants.

4. Each Participant is responsible for the costs of its participation in all cooperative activities carried out in the framework of this Memorandum, unless they determine otherwise in writing. Each Participant's participation in the cooperative activities is subject to the availability of funds, resources, and personnel.

Section 6
Commencement, Modification, and Discontinuation

1. The Participants' implementation of cooperative activities within the framework of this Memorandum may commence on the date of signature.

2. This Memorandum may be modified by mutual determination of the Participants in writing.

3. The Participants may discontinue this Memorandum at any time in writing. Alternatively, a Participant that wishes to discontinue its participation in the activities under this Memorandum should endeavor to provide at least six (6) months' written notice to the other Participant.

Signed, in duplicate, at Washington on the 21 day of December, 2011, and at Beijing on the 29 day of December, 2011, in the English and Chinese languages.

FOR THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA:

FOR THE CHINESE ACADEMY OF SCIENCES:

谅解备忘录

美利坚合众国 能源部

与

中国科学院

关于核能科学与技术合作

美利坚合众国能源部（能源部）和中华人民共和国科学院（中科院），以下简称"双方"：

注意到双方对在核能方面共同关注事宜加强沟通与合作，促进双方的科学家、实验室、研究机构和大学间的合作，和实现广泛的核能科学与技术领域的研发合作上的愿望；并

注意到于 1985 年 7 月 23 日在华盛顿签署的美利坚合众国政府与中华人民共和国政府关于和平利用核技术的合作协议，

达成以下谅解：

一、目标

1. 本谅解备忘录（备忘录）旨在推进和加快核能技术领域的科技方面的合作。

2. 经共同确认后，双方可以邀请其他单位参与在此备忘录框架下开展的合作活动，包括：政府机构、大学、科研中心、研究院所、私人企业和双方各自政府下的其他单位。其所需费用由参与单位自行负担。

3. 双方在此备忘录下的合作均仅限于和平目的。

二、合作形式

1．　　在本备忘录下的合作形式可包括：公共技术信息、数据和经验的交换；技术与管理人员的互访和短期派驻；设备、材料与仪器的交换；共同举办学术大会、研讨会或讲习班；以及双方以书面形式共同确定的其他合作方式。

2．　　人员的互访与短期派驻以及设备、材料和仪器的交换等条款应由派遣与接收单位以适当书面形式达成双方共识。

三、合作领域

1．　　优先合作领域包括如下方面：

<u>核能在非电力应用领域的合作</u>

核能可用于替换工业领域排放温室气体的燃料，例如，石油提炼需要温度在 250-500°c，而天然气蒸汽重整是热处理的温度应在 500-900°c 间，达到更高的温度效果则需要转换到新的冷却技术，如熔盐。有了先进的冷媒，可以使产出温度达到 500°c -900°c 以上。潜在领域的合作活动可包括氟化盐冷却系统的材料与化学研究。

<u>核燃料资源</u>

核能可以减少对温室气体排放和全球变暖、能源安全和反复无常的化石能源的价格上的担忧。为使核能继续作为即可性又可持续的能源资源，必须确保可获得经济性的核燃料资源。此合作的重点是直接从海水中萃取铀，虽然铀在海水中的浓度很低，3.3 ppb(十亿份率)，但是海水含有超过 45 亿吨的铀原料，这将为核燃料提供无限的资源。潜在领域的合作活动可包括 (a) 配位模型分子级别的理解，吸附机制，和铀萃取的动力学；(b)新功能配体；及(c)先进的吸附剂材料。

2．　　经双方一致书面同意，可将合作领域扩展和修改。

3．　　双方将在以书面协议形式共同确定的领域进行研究和开发工作。此类协议其中，涵盖的其他事宜当中，应包括保护和分配知识产权的条款。

四、管理

1. 对本备忘录的执行将受执行委员会的监督，执行委员会包括双方各一名主席，即能源部核能助理部长和中科院副院长。

2. 执行委员会主席应从本方各自指派一名技术协调员执行本备忘录下的相关技术活动。双方技术协调员应共同计划、确定和协调合作活动，并可针对双方共同确立的课题成立相关工作组。

3. 工作组和/或执行委员会会议每年举办一次或按双方商定择期举办，会议轮流在美国和中国举行。

4. 主办方应负责选择会议的地点并承担会议相关的费用。参与会议的双方代表应承担各自的旅费和住宿费用。

5. 双方的技术协调员应共同撰写会议报告，经执行委员会批准后，双方均有权发布会议书面报告，无需事先通知对方。会议报告应包含双方合作活动的进展情况，以及下一年延续合作的实施计划。
6. 技术协调员可以邀请其本国其他机构的代表参加工作组和/或执行委员会会议。

五、总体考虑

1. 本备忘录将不受法律约束。

2. 任何一方在本备忘录下所开展的活动均须遵守其相关法律、规定和要求，以及本国所加入的国际协议。

3. 在备忘录有效期内，任何关于本备忘录的问题均由双方通过协商解决。

4. 除非另行书面约定，本备忘录下合作所产生的费用均由发生费用的一方承担。本备忘录下所开展的活动取决于人力、已拨经费和其他资源是否到位。

六、生效、修改和终止

1． 双方在本备忘录框架下的合作在本备忘录签署之日开始实施。

2． 本备忘录经双方书面同意可予以修订。

3． 本备忘录可在任何时候由双方以书面形式终止；如一方希望终止本谅解备忘录，应提前六个月书面通知另一方。

本谅解备忘录于 2011 年12月29日在北京签署，于 2011 年12月21日在华盛顿签署，英中文版本各一式两份。

美国能源部：

中国科学院: